Improving the Cost Efficiency and Readiness of MC-130 Aircrew Training

A Case Study

Sarah E. Evans

RAND PARDEE RAND GRADUATE SCHOOL

Abstract

The MC-130 is a multi-role aircraft which plays a vital role in both times of war and peace as a key enabler of U.S. Special Operations Forces. Readiness training is particularly important for this asset, which must be ready to deploy at all times. As the U.S. Military budget decreases, the costs of training policy alternatives must be carefully evaluated to maximize readiness with the available resources. The purpose of this research is to inform decision makers about the respective effects on costs and readiness of existing and potential MC-130 aircrew continuation training policies. Frequency and duration of sorties, having a colocated simulator, the proportion of temporary duty training, and role specialization were investigated in this research. In order to accomplish this goal a literature review was conducted and a data gathering internship was carried out in the 353rd Special Operations Group at Kadena Airbase, Japan. Using the information gathered an integer linear optimization model was developed along with feasible model inputs. Cost analysis was performed for each of the policies in a variety of scenarios. Increasing the proportion of temporary duty training, and implementing role specialization policies were found to be favorable alternatives in some cases. Having a colocated simulator was found to provide the most significant savings for continuation training overall.

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Executive Summary

Demands on Special Operations Command (SOCCOM) are increasing in the midst of budget cuts across the Department of Defense (DoD). The United States Military and its unique assets and capabilities are increasingly global, joint, and in demand, all of which are characteristics of a "low density high demand asset". As the United States Military is tasked to accomplish more with fewer resources, it is important to find ways to be more efficient with existing resources in order keep accomplishing the mission. In order to take a bite out this problem, MC-130 air crew training will be used as a case study. The purpose of this research is to inform decision makers about the respective effects on costs and overall readiness of existing and potential MC-130 air crew continuation training policies.

Implementing data from an observational internship and information from literature reviews, this research employs an integer linear optimization model to find the minimum fuel required to meet currency requirements, and cost analysis in order to examine different air crew training policies. The internship observations identified key factors that influence MC-130 air crew training decisions currently to be aircraft limitations, attrition, and training resource availability. Policies levers available to affect the dependability of training resources in order to mitigate the dynamic decision making environment that characterizes MC-130 air crew training include maintaining a co-located simulator, selecting the proportion of Temporary Duty (TDY) training, and role specialization. Having a co-located simulator provides savings in every case and has particularly high savings when two squadrons share a collocated simulator, and for more costly variants of the aircraft. Higher proportions of TDY training are recommendable when training resource distances or attrition rates are relatively greater and more favorable alternative resource locations exist. TDY training is also recommendable when the political or training benefits outweigh the additional cost of training. Higher attrition results in more contingency plans and increased training costs. Similarly, as attrition from sources such as maintenance, weather, resource availability, personnel, increase, the benefits (where they exist) of a co-located simulator, and TDY training, accrue more expediently.

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Abbreviations

AAR   Air-to-Air Refueling

AD   Airdrop

AFSOC   Air Force Special Operations Command

AMC   Air Mobility Command

BAQ   Basic Aircraft Qualification

CDS   Container Delivery Systems

COTS   Commercial Off The Shelf

CSO   Combat Systems Officer

DoD   Department of Defense

EW   Electronic Warfare

FARP   Forward Area Refueling Point

GAO   Government Accountability Office

GLPK   GNU Linear Programing Kit

GCC   Geographic Combatant Command

GRASP   Greedy Randomized Adaptive Search Procedures

HAAR/TAAR [1], HT [2]	Helicopter Air-to-Air Refueling/Tiltrotor Air-to-Air Refueling
Infil/Exfil, IE [3]	Infiltration/Exfiltration
LL	Low-level
OPTEMPO	Operations Tempo
RAP	Ready Aircrew Program
RTM	RAP Tasking Memorandum
SOCOM	Special Operations Command
SOF	Special Operations Forces
TBT	Training Bundle
TDY	Temporary Duty
TSOC	Theater Special Operations Command
USAF	United States Air Force
VBA	Visual Basic for Applications

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[1] **AFSOC/A3T, "MC-130 Aircrew Training,"** *Air Force Instruction 11-2MC-130*, **Vol. 1. http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi11-2mc-130v1/afi11-2mc-130v1.pdf**

[2] While HAAR/TAAR is a common community term, for the purposes of brevity in coding and space in graphics, HT was preferred.

[3] While Infil/Exfil is a common community term, for the purposes of brevity in coding and space in graphics, IE was preferred.

Chapter 1. Introduction

SOF and the MC-130 Are Low Density High Demand Assets with a Joint and International Focus

The U.S. military's MC-130 specialized cargo aircraft plays a pivotal role in supporting the United States Special Operations Command (SOCOM) operations and its Special Operations Forces (SOF). The MC-130 is in high demand not only by SOCOM for discreet infiltration, exfiltration, helicopter aerial refueling, and SOF resupply, but also for providing humanitarian relief. According to the Government Accountability Office, "Average weekly deployments of SOF personnel have increased from about 2,900 in Fiscal Year 2001 to about 7,200 in Fiscal Year 2014."[4]

The missions supported by the MC-130 occur throughout the world. The infiltration and exfiltration mission of the MC-130 makes it particularly globally focused, as SOF must enter and safely exit whatever place is demanded by the mission. In the Pacific, especially, an important part of what SOCOM accomplishes with MC-130s is to cooperate with our international allies in exercises which are conducted as training for working together in contingency operations; i.e., military actions or operations, or in hostilities against an enemy of the United States or against an opposing military force. SOCOM forces have a worldwide presence despite their small numbers; SOCOM maintains partnerships with 60 countries worldwide.

SOCOM's global focus reflects the increasingly global focus of the Department of Defense (DoD).

U.S. forces increasingly operate jointly, and SOCOM and its MC-130s are increasingly in demand.

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[4] *Special Operations Forces: Opportunities Exist to Improve Transparency of Funding and Assess Potential to Lessen Some Deployments*, **Government Accountability Office, July 2015. http://www.gao.gov/assets/680/671462.pdf**

Although the future force will be smaller, it will be ready, capable, and able to project power over great distances. Investment decisions will ensure that we maintain our technological edge over potential adversaries, and that we advance US interests across all domains. Staying ahead of security challenges requires that we continue to innovate not only in the technologies we develop but in the way U.S. Forces operate. Innovation – within the department and working with other U.S. departments and agencies and with international partners – will be center stage as we adapt to meet future challenges. [5]

SOF and the MC-130 are good examples of assets that are "low density"; i.e., few in number and highly specialized and "high demand"; i.e., called upon often for unique and important missions. Low density high demand assets are defined as "force elements consisting of major platforms, weapons systems, units, and/or personnel that possess unique mission capabilities and are in continual high demand to support worldwide joint military operations." [6] The demands on these assets are increasing despite DoD budget cuts that reduce the resources available for maintaining their readiness.[7]

While low density high demand assets compose relatively smaller components of the overall force and budget, their unique capabilities make them pivotal to the DoD's overarching strategy. Due to their relatively small capacity and high demand, low density high demand assets must be constantly ready to deploy.

The MC-130 exemplifies a unique asset that is in high demand with a joint and internationally focused mission. It must be "ready" when called upon to perform. Readiness is the measure used

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[5] **Hagel, Charles T. "Quadrennial Defense Review." Washington, DC: Department of Defense, March 4 2014.**

[6] **William S. Cohen, Annual Report to the President and the Congress (Washington, DC: US Department of Defense, 2000), p.35**

[7] "The Department of Defense is experiencing declining budgets that have already led to significant ongoing and planned reductions in military modernization, force structure, personal cost, and overhead expenditures. The department estimates a 20% drop in the overall defense budget – including declining workforce – from the post-9/11 peak in 2010 to 2017." p. 1
"The department protected its long-planned growth of Special Operations Forces in the fiscal year 2014 budget submission, with growth across the department's FYPD mainly enhancing Special Operations Forces enablers." p.29
Defense Budget Priorities and Choices Fiscal Year 2014 page 1, 29.

to determine how prepared for the mission an organization is and varies in definition widely. The definition of readiness according to the 2011 U.S. National Military Strategy is "the ability to provide and integrate capabilities required by the combatant commanders to execute their assigned missions." [8]

It is difficult if not impossible to measure the outcomes of many military policies, because the results are only observable in the context of uncontrolled events such as war. It cannot be known how ready the U.S. military is for the next war until after the next war's unknowns are knowable. Inferences and guesses about mission readiness can be made based on the information that is available such as training outcomes. How much training is accomplished and to what standard is one measure of readiness.

The goal of practically every component of the DoD's budget is readiness.[9] Whether acquiring specialized equipment to accomplish the mission, maintaining that equipment over time, incentivizing highly skilled personnel to stay in the force, or training personnel to operate equipment, the goal is readiness. Budgets cuts negatively impact readiness in all these areas by lowering resource levels in the face of constant and often increasing demand. Increasing cost efficiency mitigates this situation.

Research Goal

This research will inform decision makers about the respective effects on costs and readiness of existing and potential MC-130 aircrew continuation training policies. (Continuation training is the periodic training required of the aircrew, after they have completed initial training, to maintain currency.) The continuation training policies that were investigated in this research are frequency and duration of training sorties, whether or not aircrew members have access to a co-located flight simulator, the proportion of training that is accomplished at a temporary duty

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[8] **National Military Strategy of the United States of America (Washington: Department of Defense, 2011), 20.**

[9] **Harrison, Todd, "Rethinking Readiness," *Strategic Studies,* Vol. 38, 2014.**

location rather than at the home duty station, and role specialization or policies based on the characteristics of and resources for each role.

Research Questions

I investigated the following research questions.

i)   What factors influence the cost efficiency of MC-130 aircrew training?

ii)   What are the cost effects of different policies for providing continuation training to MC-130 aircrew, including frequency and duration of sorties, having a co-located simulator, temporary duty training, and role specialization?

iii)   How do the costs of different MC-130 aircrew training policies compare?

Approach

To answer the research questions, I began by gathering information. I reviewed the literature related to how the organizations involved in MC-130 crew training work together and the current policies governing aircrew continuation training including how training is scheduled. I served as an intern in the position of Assistant Policy Analyst for the historian's office for over a month at the 353rd Special Operations Group which is composed of two MC-130 squadrons (the 1st Special Operations Squadron and the 17th Special Operations Squadron), the 320th Special Tactics Squadron, the 43rd Intelligence Squadron, the 353rd Special Operations Maintenance Squadron, and the 353rd Special Operations Support Squadron. (Flying squadrons are units which are composed of aircraft and their aircrews.) I was able to observe how the aircrew scheduling process works on a day-to-day basis, determine the key factors that influence the scheduling of MC-130 aircrew training, gain insight into policy alternatives available for improving the scheduling of training, and collect data.

I then developed a model to optimize training schedules and processed the data into feasible inputs for the model. Feasibility was determined by quantifying the flight planning heuristic that aircrew members implement in the dynamic decision making environment presented by the day-to-day challenges of aircrew training. The optimization model selected feasible sortie profiles that minimize the fuel necessary to complete continuation training. In this optimization, currency is a proxy for readiness and fuel cost is proxy for total costs. The optimization was run in a

variety of scenarios in order to examine a range of existing and potential policies. Following the optimization runs, the cost of aircrew continuation training was calculated and non-dollar costs and respective readiness levels were taken into consideration in order to make policy recommendations.

Scope of the Study

I studied MC-130 aircrew continuation training in the Pacific as a case study of a low density high demand asset. While this research mainly considers the MC-130J, which is the model that all MC-130 squadrons are transitioning to, it drew from knowledge of existing aircraft models (the MC-130P and MC-130H) and training practices. This work began in 2013 and reviewed literature from years 1992-2015. My work focuses on the MC-130 operators, who comprise the aircrew. The aircrew includes a pilot, co-pilot, Combat Systems Officer (CSO), and two loadmasters. In order to do their jobs, these aircrew members must complete continuation training regularly according to Air Force Regulations; in this study I worked with the regulations that were in place at the time of my internship.

Organization of this Document

Chapter 2 provides important background information. It describes SOCOM, SOF, and the role of the MC-130 in more detail. In doing so, it places SOF and the MC-130 in the context of low density high demand assets and their importance in today's environment of irregular warfare. [10] And it explains why a study of the schedules and costs related to training aircrews for the MC-130s operating in the Pacific might offer recommendations applicable to crew training for the MC-130J (next in the line of MC-130s), and to other low density high demand assets.

Chapter 3 identifies the key factors that influence MC-130 aircrew continuation training and describes the training in some detail. The chapter also discusses the policy alternatives that are available for improving MC-130 aircrew training.

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[10] **DoD, "DoD Instruction Number 3000.07: Irregular Warfare," 28 August 2014.**

Chapter 4 describes the methodology I used to address the research questions. It consists of a literature review, internship on site at the 353rd Special Operations Group, development of an optimization model, and computer-based data analysis.

Chapter 5 describes the results of my analyses. First, the background and methodology aspects unique to the development of the different policy analyses of the model will be discussed individually in detail. Each discussion will be followed by the findings of the analysis of each policy. Then selected integrations of the policies will be examined. Finally, all the policies will be compared on the basis of cost and readiness.

Finally, in Chapter 6, I present the conclusions from the research and suggest policies related to MC-130 aircrew training schedules that the DoD and the Air Force could implement to promote crew readiness and training cost effectiveness.

Chapter 2. MC-130 Background

About SOCOM

The DoD established SOCOM in 1987 in order to oversee Special Operations Component Commands for the services and to provide the training and resources needed to fulfill unconventional missions. Special Operations Command originally was dependent on the services for funding which resulted in less and less funding, but the DoD decided to make a separate entity with its own budget in order to continue to provide unique capabilities.

The structural and cultural differences between the DoD and SOCOM are evident today. According to Susan L. Marquis's book, *Unconventional Warfare: Rebuilding U.S. Special Operations Forces*, "Despite the 'joint' character of most special operations missions, special operations forces are stationed and structured in accordance with the tradition of their parent services."[11] For MC-130s, the issues that result from this overarching structure are particularly evident. As SOCOMM assets, MC-130s not only participate in Air Expeditionary Force (AEF) cycle deployments but also support Army and Navy SOF units' deployments which are governed by separate cycle in the Joint Operational Readiness and Training System. [12]

The AEF cycle is an Air Force construct that governs the deployment schedule for the majority of the Air Force, but not low density high demand assets such as the MC-130. The AEF cycle was developed and implemented in order to provide more predictable deployments for service members to address readiness issues associated with unexpected deployments. Conventional assets rotate between peacetime operations, deployment preparation, and deployment. SOF assets must be ready to deploy at all times. At the same time that funding is decreasing, the

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[11] **Marquis, Susan Lynn, Unconventional Warfare: Rebuilding U.S. Operations Forces: Brookings Institution Press, 1997. 260**

[12] **Kingsley, Michael J,** *Transformation Dilemma: Air Force Special Operations Command and the Role in the Future of the Air Force and Special Operations***, DTIC Document, 2003. p.39**

military as a whole is approaching the need to be ready the majority of the time much like these low density high demand assets.

MC-130 operators in the Pacific constantly have to make contingency plans not only for regular attrition factors such as weather, but also being bumped for training resources like drop zones which are shared with multiple organizations. In the Pacific, resources are particularly constrained today due to a natural disaster and politics in the 1990s. The MC-130s were originally stationed at Clark Air Base in the Philippines, where the geography is well suited for MC-130 continuation training. However, in 1990 a volcanic eruption forced the wing to evacuate to Kadena Air Base in Okinawa. Subsequently, the Philippines decided not to renew the lease of Clark Air Base, so the MC-130s could not return. Several locations were considered for an alternate basing location. Although Kadena was disadvantageous for training, it was found to be the most viable option. [13] Therefore, studying the MC-130 aircrew training in the Pacific is valuable because this is an environment where training is especially difficult.

Irregular Warfare Increases Demands on SOCOM

The nature of contemporary conflicts, in which non-state actors wage unconventional war, has increased the demands on SOCOM. In the past, conflicts largely were fought between nations and within national borders. But on October 7, 2001 the United States began a Global War on Terror in response to the events of September 11, 2001. The responsibility for fighting the Global War on Terror was delegated to SOCOM. [14] Special Operations Forces had played

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[13] "While offering essential location in the Western Pacific, excellent quality-of-life factors, long-tours, and political stability, its only drawback was the lack of training areas. Even so, Kadena was close enough to Korea to do a significant amount of the wing's training there."

Marion, Major Forrest L., *Ash Warriors: The Relocation of the 353rd Special Operations Wing June-December 1991*, Hurlburt Field, Florida, Office, Headquarters Air Force Special Operations Command History, AFD-051228-013. p.24

[14] "To effectively prosecute DOD's efforts against terrorism, Secretary of Defense Donald H. Rumsfeld wanted a single headquarters— USSOCOM—to have primary military responsibility for the Global War on Terrorism. In July 2002, Secretary Rumsfeld directed USSOCOM to develop a plan to find and deal with the international threat of terrorist organizations. For the next three years, during the tenures of General Holland and his successor, General Bryan D. "Doug" Brown, USSOCOM would work to win support for

important roles in recent conflicts, which likely influenced SOCOM's selection for this important strategic task.

Today, globally dispersed networks seek to achieve their ends through attacks like the September 11 attack on the World Trade Center. Special Operations Forces have played an important role in many successful operations because their unconventional organizational structure allows for the flexibility and unique capabilities needed to face unconventional threats.

One commentator noted, "Reliance on external nations and allied partners, coupled with the strategic direction to employ innovative, low-cost, and small-footprint indirect approaches to prevent conflict, have made SOF [Special Operations Forces] a resource of choice for both Combatant Commanders and military strategists."[15] Use of Special Operations Forces has also been the preferred approach of the current president, Barack Obama, and administration in the midst of popular discontent with war in general and particularly conventional war.[16,17] They have been used in strategic and tactical roles to a greater degree than ever before.

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its efforts to be the lead unified command for planning and synchronizing the GWOT. This would not be an easy or quick process."
***History of SOCOM*, HQ USSOCOM: United States Special Operations Command, 2007. http://fas.org/irp/agency/dod/socom/2007history.pdf, p.14**

[15] **Grespin, Whitney, "From the Ground Up: The Importance of Preserving SOF Capacity Building Skills," Journal of Strategic Security, Vol. 7, No. 2, 2014, p. 38**

[16] "the Obama administration has placed a premium on the use of these elite units for complicated missions in places like Yemen and Somalia"
Weisgerber, Marcus, "Peeling the Onion Back on the Pentagon's Special Operations Budget," 2015. http://www.defenseone.com/management/2015/01/peeling-onion-back-pentagons-special-operations-budget/103905/

[17] "…but Americans have shown little appetite to support another large-scale overseas military effort – and Pres. Obama vowed in his State of the Union message that America would not occupy other nations on his watch. So the Pentagon is working 'why, with and through' allied and partner nations to enhance global security, to use the current catchphrase"
Shanker, Thom, "Military Sees Broader Role for Special Operations Forces, in Peace and War," *The New York Times*, April 2, 2013.

Readiness is More Important than Ever

Continuation training for MC-130 crew members—the ongoing training they receive to keep their skills up to date—is crucial to maintain readiness. It is important to take a close look at the training and to find ways to provide what is needed cost effectively.

The military is an organization for which it is difficult to measure outcomes, and so it is difficult to measure how well MC-130 aircrew training ensures the aircrew's readiness. The desired outcomes of the military are, at the best end of the spectrum, peace and stability, and at the worst end of the spectrum, success in times of war. When there is peace, the military is preparing for the next war and working to promote stability. Both of these desired outcomes are challenging to measure. Peace and stability are the results of myriad factors besides military operations.

It is difficult to say how prepared the military is for a war that has yet to happen. Not only is it difficult to predict when the next war will occur, it is extremely difficult to predict what will happen. Therefore current metrics for measuring readiness are imperfect. In the military it is common to estimate readiness based on the available assets. However, it is not a good practice to say that because you have certain assets, you are "ready" because in reality readiness implies the ability to employ these assets in a dynamic decision-making environment.

It is possible that new metrics for readiness could be developed. For instance, in the case of the MC-130, no regulation mandates that aircrew members must keep track of the number of events accomplished on the amount of fuel that was allotted. The aircrew members have begun keeping track of this metric in order to justify expenditures and capture their accomplishments. It is likely that metrics such as this could make a difference in more accurately measuring readiness.

One of the primary differences between low density high demand assets and conventional assets is the fact that low density high demand assets must be ready at all times to support global operations. One of the ways that Special Operations Forces has dealt with the need to be ready all the time, is training people in multiple jobs in order to compensate for the fact that there are not enough people to do everything. For instance, in the MC-130 flying squadrons, schedulers are also aircrew members. It is difficult to maintain consistency throughout the planning process when multiple people share the duties of individual jobs. These issues will likely be faced by

other military services and programs as well, so addressing them in Special Operations should benefit DoD more broadly.

Readiness includes the ability to function well even when "task saturated"; i.e., when one's focus is divided among multiple jobs and multiple objectives, when there is more than any one person can do, and one must correctly identify what is most important and then focus on it. Practice in being task saturated is good preparation for war, and military personnel should be trained in how to function in a task-saturated environment.

It is more important that the MC-130 aircrew members are able to execute the mission in a task-saturated environment than be able to execute office chores in a task-saturated environment. Therefore, it would be better to divert resources to actual training than to the complicated contingency planning and dynamic decision-making that currently govern the scheduling process. And it might be best to make home operations more efficient in order to divert more resources to increasing readiness in situations that are more similar to war where task saturation is different, absolutely required, and relatively more important.

Overall in the United States military, it is estimated that readiness is waning in the post Sequestration, budget cut implementation period.[18] While information on the readiness of Special Operations Forces is not readily available, it is clear from historical information that demand has increased over time. This demand has resulted in increasing deployments and decreasing retention and readiness. [19] This effect will be compounded as the individual services,

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[18] "Readiness levels already in decline from this period of conflict were significantly undercut that implementation of sequestration in fiscal year 2013, and the force is not kept pace with the need to modernize."
Hagel, Charles T. "Quadrennial Defense Review." Washington, DC: Department of Defense, March 4 2014.

[19] "Several SOF units appear each year on the Secretary of Defense's "Low Density, High Demand" assets list, a designation meant to identify top priorities for resource additions. As early as 1994, a Government Accountability Office (GAO) study found that, "as a result of factoring increased peacetime demands into [SOCOM's] joint mission analysis, about 50 percent of the Command's planned force structure is for peacetime forward presence in key regions of the world". From that point in time, overseas deployment of SOCOM personnel had already doubled by 1996–7. The GAO revisited this topic in 1997 in a new report and concluded that there was some indication of degraded readiness in SOF units. Over the same period, retention rates in some units also began to decline. More recent data on SOF OPTEMPO and readiness are

from which Special Operations Forces draw its personnel are cut as well.[20] As readiness is threatened by decreased resources and ever increasing demands, the airpower that enables Special Operations Forces becomes all the more vital to preserving the mission of rapid global deployability. [21,22]

The Budget Control Act of 2013 introduced substantial budget cuts to the DoD, and the DoD has decided to "reduce force structure in order to protect and expand critical capabilities, modernizing the forces, and investing in readiness."[23] These decisions highlight the paradox of

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not publicly available, but officials in the Pentagon and in Congress indicate that SOF units are now being demanded and deployed at peak historical levels."
Fitzsimmons, Michael, "The Importance of Being Special: Planning for the Future of US Special Operations Forces," *Defense & Security Analysis,* Vol. 19, No. 3, 2003, p. 203-218. p.35

[20] "End strength cuts imposed on the Services could adversely affect the pool of volunteers from which special operators as drawn and these cuts, in addition to impacting special operations units, might also affect the TSOCs and enabling units provided by the Services that support USSOCOM. While on a by-Service basis individual unit cuts might seem innocuous, collectively, they could have a highly detrimental impact on USSOCOM and its ability to support the GCCs."
Feickert, Andrew, *US Special Operations Forces (SOF): Background and Issues for Congress*: DIANE Publishing, 2010.

[21] "As the activity of each of these units grows, so do the demands for the aircraft, aircrews and other personnel that support them. SOF depends on its air assets for some of its key capabilities, such as rapid deployability, penetration of denied areas, and stealth. Planners should ensure that the airlift, fire support and intelligence-gathering capabilities of SOF aviation not only grow in line with overall SOF force structure, but are provided with the research and development and procurement support that has enabled their innovation and excellent performance in the past. Current administration efforts have also recognized this area as a priority for additional investment."
Fitzsimmons, Michael, "The Importance of Being Special: Planning for the Future of US Special Operations Forces," *Defense & Security Analysis,* Vol. 19, No. 3, 2003, p. 203-218. p.205

[22] "Two principal features of the domestic and international environment forecast the likelihood of ongoing high demand for special operations forces to achieve U.S. national security objectives: U.S. budgetary pressures and the continued prevalence of irregular threats. The United States will likely face continued fiscal constraints, which place a premium on cost-effective approaches to national security."

Council on Foreign Relations The Future of Special Operations Forces p. 5

[23] **Hagel, Charles T. "Quadrennial Defense Review." Washington, DC: Department of Defense, March 4 2014.**

having higher expectations to accomplish more with fewer resources. It is increasingly important that sustainability of operations be achieved through increasing efficiency of resource allocation.

Why It Is Important to Study Low Density High Demand Assets

The current global posture of United States forces, the likely nature of future conflicts, and the political stance of the American people and the American government all indicate a shift away from conventional warfare, preferring instead flexible footprints and allied cooperation and communication. This is not to say conventional forces should exactly replicate Special Operations Forces.

The low density high demand nature of SOCOM necessitates dynamic decision-making and substantial contingency planning. Those who manage SOCOM and work in the Special Operations Forces have been adaptive and resourceful in order to function and meet the requirements of the SOCOM mission. Many observers have come to the conclusion that SOCOM is one of the most cost-efficient segments of the armed services.[24] By studying Special Operations Forces, recommendations can be made to help the rest of the military as it is required to function as a low density high demand asset in today's budget and political environment. By making the most cost-efficient part of the services as efficient as it can be and applying the lessons learned to the rest of the military, the U.S. military can be prepared for the eventualities necessitated by any future budget cuts and the need to be ready at all times for a perpetually changing mission.

The MC-130 fulfills important needs in both conflict and peacetime. Historically, Special Operations Forces' MC-130s have played important roles in numerous conflicts and tactical operations including Vietnam, the Gulf War, Operation Just Cause, and Operation Iraqi Freedom.[25] The MC-130's primary role consists of infiltration, exfiltration, and helicopter aerial refueling, but this platform is increasingly being implemented for humanitarian efforts such as

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[24] "One of the most cost-effective elements of the defense arsenal, special operators are mature and highly skilled." **Robinson, Linda, "The Future of Special Operations,"** *Foreign Affairs,* **Vol. 91, No. 6, 2012, p. 110-122.**

[25] **Thigpen, Jerry L., The Praetorian STARShip The Untold Story of the Combat Talon: Air University Press, 2001. http://www.au.af.mil/au/awc/awcgate/au/thigpen.pdf (xxxi-xxiv)**

Operation Tomodachi and typhoon Haiyan relief. As the defense budget environment contracts, the flexible, tactical, and precision role of the MC-130 is becoming all the more important for the national security of the United States as a whole. This research seeks to inform robust decision making by exploring training scheduling policies under resource constraints.

Due to the pivotal role of the MC-130, there are many stakeholders interested in it and resources were available to look at this low density high demand resource. In order to learn about this asset an internship at the 353rd Special Operations Group was accomplished. The 353rd Special Operations Group is under AFSOC which is under Special Operations Command. The 353rd Special Operations Group includes two flying squadrons, the 1st and the 17th Special Operations Squadrons.

The 353rd Special Operations Group is stationed at Kadena Air Base, Japan. The 353rd Special Operations Group is the only AFSOC unit in the Pacific and supports all Air Force special operations and many joint and allied special operations as well. As an overseas unit, the 353rd Special Operations Group does not yet have a co-located simulator. Additionally many training resources are based upon agreements with other services, other units, and other countries. In part due to the location, many of the training resources needed to accomplish various training events are unreliable. (A training "event" is an individual task that must be completed to achieve the goal of the training.) As a result, numerous contingency plans usually are developed in the process of planning and conducting a mission. Furthermore due to the fact that the training resources needed tend to be farther away a lot of training flight hours are spent flying to resource locations, or in other words, in transit rather than in training. For the 353rd SOG, a flight simulator is particularly important because of the large quantity of time spent flying to training resources.

As the MC-130Js are delivered, the 1st Special Operations Squadron is taking on the role of the 17th to a greater degree so they can continue to meet the needs of their partners during the transition to the J model aircraft. This is being accomplished so that the steady demand for helicopter aerial refueling will continue to be met as the MC-130 P is phased out and the MC-130J is being integrated. This does not mean that the 1st Special Operations squadron was not meeting its currency requirements for this specialized task. Respectively, the 1st Special

Operations Squadron had fewer people that were qualified with the appropriate upgrades to accomplish this task because the responsibility was primarily delegated to the 17th Special Operations Squadron. In order to meet the demand for helicopter aerial refueling during the transition, more people needed to train in order to have aerial refueling qualification. Once a qualification for certain task has been obtained more currency requirements must be met over time. However as an aircrew member becomes more experienced the currency requirements lessen.

AFSOC is an organization which is also a stakeholder for this research because they make the decisions about training policies, resource allocation, and funding. For example, AFSOC gets to decide when and whether or not overseas units get co-located simulators. Additionally AFSOC also sets the training requirements for all the units. This is the organization from which the Ready Aircrew Program Tasking Memorandum (RTM), for the MC-130J originated. The RTMs are policy documents which govern all MC-130 aircrew training. Interestingly, simulator training is just now becoming an emphasis and has been added to RTM to a greater degree and is now being included in the data that is kept on training. AFSOC makes the overarching budgetary decisions for all the Air Force special operations units. Therefore this work will likely have implications for many of their aircraft which are not on the Air Expeditionary Force cycle and are low density high demand assets.

The Services as a whole are stakeholders in this research because the implications of this methodology are applicable for multiple air frames. This research will establish a framework for optimizing aircrew training policies for multi-person crews given unique capabilities and resource sets. This methodology will utilize metrics such as fuel dollars per training event accomplished.

MC-130 aircrew members themselves have a big stake in this problem because these decisions will affect their everyday lives, how they accomplish the mission, how they train how much time they have to spend with their families, and how ready they are to accomplish whatever task is set before them. The general stereotype is that aircrew members prefer not to have simulators because simulators are not as good training as being in the actual aircraft. There is certainly some truth behind this perspective which will be discussed in the section which addresses the

pros and cons of the use of simulators. However, it is questionable whether or not this is the dominant perspective in the 353rd Special Operations Group as a result of the "tyranny of distance," which necessitates much travel time in order to accomplish training. In this environment training is most of what aircrew members do on a day to day basis unlike other environments. For instance, Mildenhall Air Force Base is an example of where actual missions are the dominant task. Training serves the multitude of purposes beyond just meeting the requirements set out by the RTM. For instance the RTM places no requirements on training with joint forces or allies, but that is important part of what is accomplished in this region.

Maintainers of the MC-130 have a great deal of stake in this research as well because anything that affects how the aircrew members do business will affect how much maintenance needs to be accomplished. The frequency of sorties, the time between sorties and the amount of time needed for maintenance all affect the amount of effort and work that must be accomplished. As a maintenance squadron that must keep the aircraft deployment ready at all times, there is constant stress to maintain readiness levels. In contrast to the existing ageing fleet of MC-130s the new variant will require significantly less maintenance. Appendix A shows availability rates from MC-130Js at Cannon Air Force Base.

The lower maintenance load does not come without a learning curve however. Maintainers must learn how to take care of an entirely different aircraft. Preparations have been underway for some time. The majority of maintenance training is being conducted in the US which makes the transition more difficult.

Because of the current stakeholder interest in Special Operations Force and particularly the MC-130J (the newest variant of the MC-130), the resources to study this particular low density high demand asset have been available to facilitate this research. Studying this asset now could help with the current transition to the MC-130J by identifying training policies which are advantageous in the long term.

Chapter Summary

This chapter provided background information about the role of the MC-130 in the overarching context of SOCOM. Next, this chapter discussed how the readiness demands on SOCOM are

increasing. The chapter also highlighted how DoD budget cuts will affect SOCOM. The importance of studying low density high demand assets was then brought to light, followed by a section on why the MC-130 in particular is a good asset to study.

Chapter 3. Aircrew Training and the MC-130

About the MC-130

The MC-130 is a mid-sized turboprop cargo aircraft with very specialized features. The basic C-130 is a cargo aircraft whose primary function is tactical airlift. There are many specialized variants of the C-130 with a variety of missions, such as aerial tanker (KC and HC-130s), command and control (EC-130s), search and rescue (SC and HC-130s), reconnaissance (RC-130s), electronic warfare (EC-130s), gunship (AC-130s), and special operations (MC-130s). The 'M' in MC-130 stands for multi-role, and the MC-130 combines many of the missions of the C-130.

The primary functions of an MC-130 are infiltration, exfiltration, helicopter air-to-air refueling, and Special Operations Forces resupply. The MC-130's equipment can be configured in a variety of ways to meet the needs of the mission at hand. For instance, the back of the aircraft could be filled with cots for medical patients. The newest edition or model of the C-130 is the C-130J. Correspondingly, there is a MC-130J. This study uses information from how training is currently conducted with MC-130H's and MC-130P's and how training will be conducted with the MC-130J's. The MC-130H's are, on average, 25 years old. The MC-130P's were originally procured during the Vietnam War and are being replaced by the MC-130J's. Where possible, information for the MC-130J model was preferred in the analysis. The reason for this preference is that the entire fleet will be migrated to this version of the aircraft in the future.

Crew Positions and Squadron Jobs

For the MC-130J there are four aircrew positions (for a total of 5 aircrew members). They are the pilot, copilot, Combat Systems Officer (CSO), and two loadmasters. Previous versions of the MC-130 (H+P) also had an electronic warfare officer, a navigator and a flight engineer.

In general a pilot's job is to fly a plane. As Aircraft Commanders, Air Force pilots are responsible for planning the missions, flying the missions, making decisions, and commanding the missions. Pilots have diverse responsibilities. For instance, they may also be squadron

commander, director of operations, quality control supervisor, training evaluators, instructor pilots, or schedulers to name a few of the roles.

Not only are there more training events required of MC-130 pilots, the events are more diverse and demanding than those for the pilots of other types of aircraft. Many are conducted specifically at night. Co-pilots assist the pilot during flight and are relatively less experienced.

CSOs responsibilities combine the eliminated roles with the help of specialized technology. The CSOs handle the navigator role, monitor radios in the electronic warfare officer role, monitor the system and engine indicators in the role of flight engineer, as well as operate the refueling system.

Loadmasters manage the safe and proper rigging and release of the equipment and/or personnel on the plane.

All of these professionals have completed initial training and gain experience through continuation training. Those with the most experience in each of the crew positions instruct, evaluate, and mentor those with less in order to cultivate readiness.

MC-130 Aircrew Continuation Training

A multi-role aircraft such as this one requires a wide breadth of skill from its operators. Therefore training for this aircraft is especially important. Furthermore since the squadrons are smaller due to the fact that there are not many MC-130s in the Air Force, compared to other aircraft in the inventory, this causes every crew member to also have more squadron responsibilities.

In order to prepare for the mission, aircrew members complete regular required training on a semiannual cycle. A training event is a requirement set out by the RTM for an aircrew member to perform certain task to certain standards on a regular basis.

This study focused on one of the two types of training required of MC-130 aircrew after they have completed their initial training. For instance, once pilots learn how to fly they must maintain and improve their skills with continuation training. Aircrew members also acquire new

skills through upgrade training. Each additional qualification, or skill, requires additional and ongoing continuation training.

Continuation training consumes the majority of training and was the focus of this research. Continuation training applies not only to pilots but to the entire crew. Notably, pilots make up the majority of the continuation training events conducted in the aircraft.

Goals of the Training

When talking about continuation training, three terms are especially important: currency, proficiency, and readiness.

Currency. Currency is a measure of whether aircrew members have completed the requisite training as outlined by the RTM. The RTM specifies the training necessary to achieve and maintain currency for every aircrew position and experience level. Currency means the crew member is up to date in their training and qualified fly at their respective qualification level.

Proficiency. Proficiency is a measure of whether or not a crew member demonstrates expertise in executing particular tasks. Proficiency is determined by commander judgment.

Readiness. The RTM defines requirements for aircrew currency, but ultimately its goal is readiness. Readiness can be defined many different ways, but basically readiness is a measure of whether or not a unit is prepared given a particular scenario that arises.

In other words, currency is completing a list of tasks. Proficiency is the ability to accomplish those tasks well. Readiness is effectively making use of those skills in real world contingencies.

Experienced aircrew members may attain proficiency with less training than required by an inexperienced aircrew member. The RTM accounts for experience level, but in practice more training is allocated to less experienced aircrew members than is outlined by the RTM requirements.

It seems reasonable to think that proficiency in a given task is a necessary part of readiness, but meeting the RTM requirements does not imply proficiency or readiness. The requirements established by the RTM do not optimize readiness. Of course, designing training that is optimal

for meeting every goal and ideal for every individual would be very difficult because every individual's training needs are unique.

While currency does not imply readiness, it is a good proxy for readiness. Where readiness is hard to define, currency is well-defined. Everyone has the same currency standards whereas readiness is different for every individual. Where readiness is hard to quantify, currency is quantifiable and measured on a regular basis to ensure everyone is meeting standards. This research uses currency as a proxy for readiness. Studying how currency is achieved gives insight into how readiness can be achieved and measured.

Components of the Training

In general, there are several types of continuation training. First there is ground training, which is not conducted in the aircraft. Next, basic aircraft qualification consists of the training events associated with basic flying, not pertaining directly to a mission. Finally, there are the mission flying requirements which consist of the training events specialized to prepare crew members to accomplish the mission.

A sortie consists of takeoff, the flight itself, and the landing. All sorties, regardless of type, include at least one takeoff, approach, and landing—basic aircraft qualification elements. Sorties also may include mission flying requirements. Many activities fall into this category, such as an airdrop or aerial refueling. I refer to two types of "sortie profiles." The first is a pilot proficiency or "PRO" sortie which is composed of basic aircraft qualification elements, usually lasts three to four hours and is conducted in the local area. The second type of sortie profile, is a combat mission profile, and is generally referred to as a "TAC" sortie, which is short for tactical. Combat mission sortie profiles usually last six to seven hours and are composed of mission flying requirements.

Mission flying requirements for the MC-130 include airdrop, air-to-air refueling, helicopter and tiltrotor refueling, flying in formation and at low-levels, infiltration and exfiltration, and establishing a Forward Area Refueling Point (FARP). It should be noted that FARPs are established on the ground rather than the air. A typical flight may consist of takeoff, transit time to training location, airdrop, aerial refueling, low-level, an approach, transit time returning to

base, landing and then establishing a FARP. The order in which these events are accomplished is determined by geography, darkness, location, and resource availability. The Figure 3.1 below illustrates the components of an MC-130 sortie.

Figure 3.1 Components of Sortie
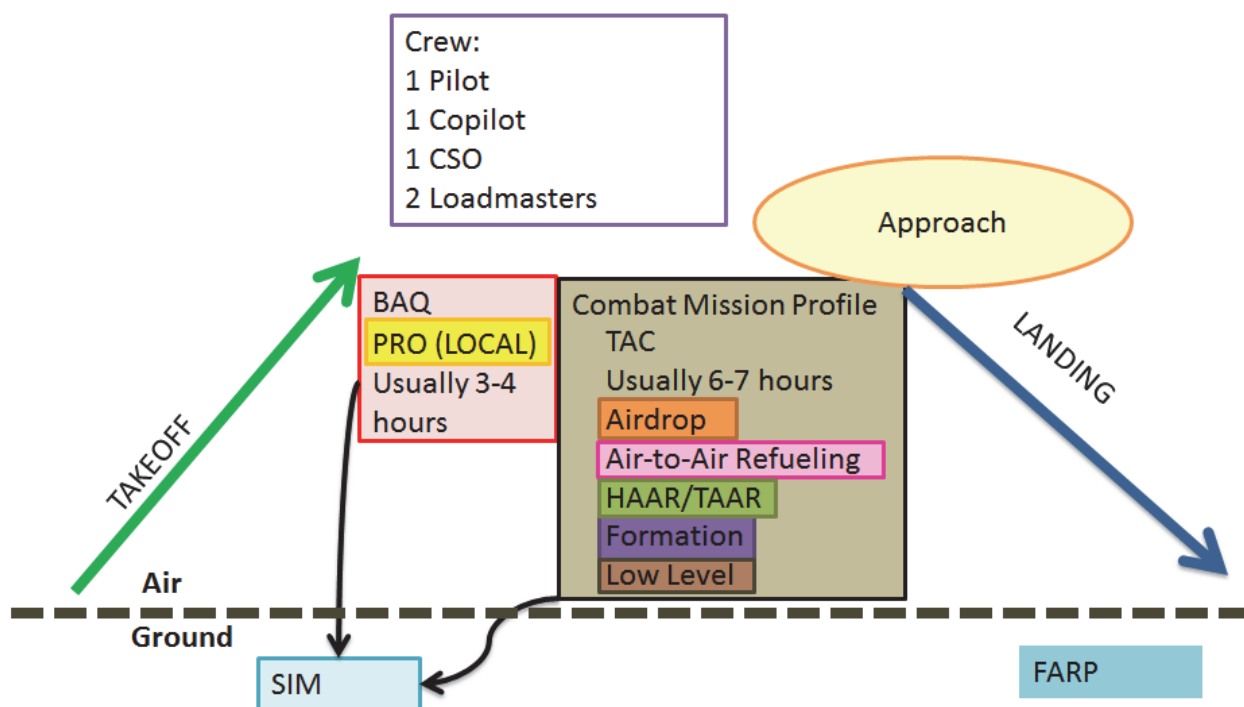
Figure Note: BAQ= Basic Aircraft Qualification,
HAAR/TAAR = Helicopter Air-to-Air Refueling/Tiltrotor Air-to-Air Refueling,
SIM= Aircraft Simulator

Current Process for Scheduling Training

The current scheduling process involves three main stages after the Flying Hour Program is established. The Flying Hour Program is a budgeting process that estimates how much flying time is required to accomplish basic aircraft training and combat mission-specific training and meet the goals of readiness, proficiency, and currency. The first two stages plan a year to a month ahead of time and include major exercises with other countries, and mission requests from various organizations such as aeromedical evacuation units and Navy SEALS. The final stage is completed on a weekly basis, usually the Friday prior to the week of interest. This is the part of

the process where the crew assignment component comes into play. Scheduling is an additional duty of the aircrew members.

Figure 3.2 Three Main Stages in the Scheduling Process

Long Range Calendar
- Takes into account holidays, major exercises, and mission requests

Monthly Calendar
- Flying days established via collaboration between Operations and Maintenance Squadrons

Weekly Schedule
- Where crew assignments are accomplished
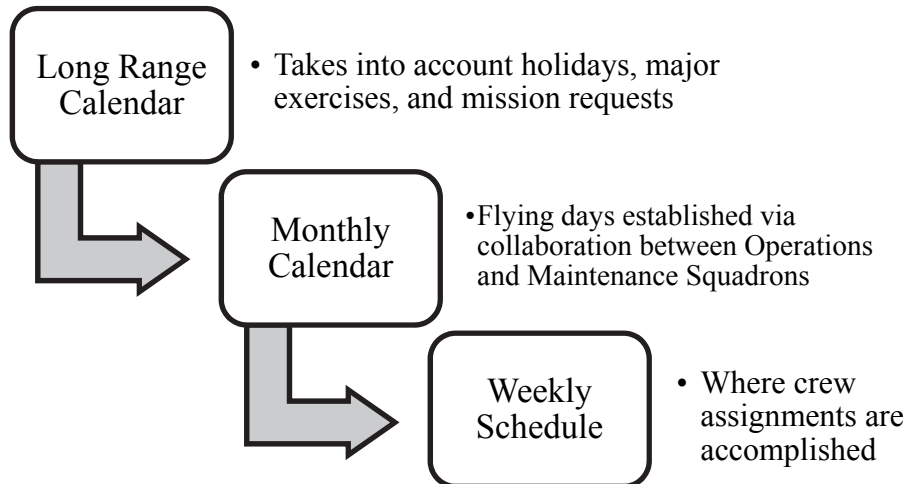
Key Factors That Influence MC-130 Aircrew Continuation Training

Many factors influence the scheduling of MC-130 aircrew training. The key factors are limitations of the aircraft, attrition, and resource availability.

Aircraft Limitations

Flight planning for any type of flight including aircrew training is constrained mostly by limitations of the aircraft related to the plane's weight, crew availability and expertise, maintenance, the weather, and political agreements. Aircraft limitations are known factors that govern scheduling based on regulations. For example, if component x of the plane is broken it is not allowed to fly or when the winds blow at y the plane is not allowed to fly.

One factor that particularly influences flight planning is the weight of the aircraft in a variety of situations. The maximum weight determines how much equipment and fuel can be on the aircraft along with the personnel for a given sortie. The maximum weight of the aircraft must meet different standards for different scenarios. In an actual mission, the aircraft can be at its full weight capacity. In training, the aircraft can weigh only what is allowed in training regulations,

which is less than mission standard weights. Additionally, for certain type of events, weight standards must be met. An example of this is tactical maximum effort takeoffs and landings.

Aircraft range depends mostly on how much fuel is on board. In some cases, the plane can be refueled in the air to extend the flight; however it is important to note that this is not typically practiced in training. Additionally, range depends to some degree on the human element; the crew can function only for so long. They are limited in the amount of time they can participate in training by regulations related to the length of the crew members "duty day." Generally sorties are not longer than eight hours. Training sorties are usually four to six hours.

Another factor which goes into planning aircrew training is the maintenance needs of the aircraft. The majority of maintenance occurs regularly according to a schedule determined by the maintenance squadron. Planes can fly with certain things broken but they may be limited in what events they can complete due to the configuration of the plane and the functionality of the components of the plane.

Aircrew continuation training scheduling also is limited by weather. While the MC-130 is an aircraft that is made to fly in lowlight conditions and bad weather, many conditions are outside the range of what is allowed for the plane to fly. For instance, if wind speeds get too high or extreme weather hits, the plane might not be allowed to fly.

For overseas duty stations especially, political agreements determine when and where training can take place. For example, depending on the location, there might be noise and visibility factors to consider. In Japan, planes are allowed to fly only at certain hours because of the noise they generate. The purpose of this policy is to ensure that locals are not unduly disrupted by operations. As MC-130 training is largely conducted at night, this is especially troublesome. Training is often conducted as soon as it gets dark to make the most of the limited time available.

Attrition

Attrition occurs when training is planned but not completed.

There are many sources of randomly arising attrition that contribute to the dynamic decision-making environment of MC-130 aircrew training scheduling. Maintenance, weather, aircrew attrition, cost of business sorties, and resources availability all contribute to attrition.

Cost of business sorties are composed of ineffective sorties, non-training sorties, and sorties needed to support unit training such as upgrades sorties. In other words, the cost of business sorties are all the sorties that do not contribute to aircrew continuation training. Units usually plan a factor of 20 percent for cost of business sorties.

Maintenance attrition occurs as a result of unplanned demand for repairs, such as when something breaks unexpectedly. The metrics on when an unexpected break occurs are carefully kept by the maintenance crew. However, training schedulers do not keep a corresponding record of how much the unexpected breaks actually affect training. Therefore, the probabilities of a break occurring are known, but the probability of attrition due to a break is not recorded and analyzed.

As previously mentioned, the aircrew is limited by the fact that they are human and can persist for only so long. Aircrew members can affect flight planning in other ways as well. They may have illnesses, injuries, or life events that would prevent them from flying at a particular time. Aircrew members could also be unable to fly certain types of flights due to their respective qualification levels or currency in those qualifications.

Resource Availability

MC-130 aircrew training is dependent on a wide variety of resources. They include a drop zone, tankers to receive fuel from, helicopters to give fuel to, signals such as radar with which to practice using the sensor equipment in the aircraft, terrain suitable for low level, and a location to conduct infiltration and exfiltration training. For MC-130s particularly, there is even more complexity in scheduling because it is reliant on joint SOCOM partners. For example, the primary drop zone utilized for training is owned by the Marines. This means that other services are involved and must be available for certain types of training. For all of SOCOM the MC-130s play an important role in getting special operators to where they need to go.

A lot of what MC-130s do, especially in the Pacific, is of international nature. Operating with the other countries' services, which have different cultures, languages, and policies of their own, adds significant complexity. International agreements and policies govern these relationships, so whether or not a drop zone is available can be a matter of international policy.

Many resources are required to accomplish the different training events in MC-130 continuation training. Combat mission training is conducted in eight main categories: airdrop, air-to-air refueling, helicopter and tiltrotor refueling, flying in formation, electronic warfare, low-level flying, infiltration/exfiltration, and establishing a FARP. Each of these is dependent on certain resources.

Airdrop. Airdropped items fall into two main categories, equipment and personnel, and range from heavy equipment to information pamphlets, from medical supplies to parachutists. No matter what is being dropped, there must also be an available drop zone in which the people and/or equipment can land. Furthermore certain conditions must be met on how these things are loaded and released which is dependent on aircraft configuration as well as the loadmasters. Also in order to conduct an airdrop, there must be someone to recover whatever is dropped in the case of the training event.

Air-to-air refueling. In order to conduct aerial refueling one must coordinate with the tanker aircraft and his chain of command. Also one must coordinate to have access to the aerial refueling track which is basically the airspace used to conduct aerial refueling. Crewmembers must also be qualified in the aerial refueling. This does not pertain to all the crewmembers necessarily, just those specified by the RTM. Another resource that must be considered when conducting aerial refueling is the amount of fuel that must be taken on the plane during the process. Depending on the amount of fuel, it must be accounted for during the mission planning process and not exceed weight limitations.

Helicopter and tiltrotor air-to-air refueling. Similar to air-to-air refueling, helicopter and tiltrotor refueling require coordination with the helicopters and their chain of command. In order to conduct helicopter and tiltrotor refueling access to the area in which helicopter and tiltrotor refueling is conducted must be coordinated with the appropriate parties. For helicopter refueling,

the amount of fuel distributed to helicopters needs to be taken account for in the flight planning process.

Flying in formation. To conduct formation training, coordination with the parties in the formation is required. Formation may be conducted with a variety of aircraft including MC-130s and helicopters. Each of these aircraft must meet maintenance standards of some kind in order to participate in the formation. Formation does not need to take place in a specific place but requires additional planning coordination for landing and takeoff and spacing between aircraft.

Electronic warfare. Electronic warfare requires access to various ranges that emit signals that simulate what might happen during a mission. In order to get access to these ranges the schedulers must coordinate with their owners and their chain of command.

Low-level flying. Mountainous low-level training requires specific terrain to accomplish properly. The MC-130J RTM specifies this training must occur in a "mountainous route" that "requires significant terrain avoidance."[26] The geography of the region limits the amount of training available and the difficulty of getting access to the proper terrain.

Infiltration and exfiltration. To accomplish infiltration and exfiltration training location is important. Equipment needs to be either loaded onto or taken off of the plane and very quickly and the plane needs to get off the ground again. Therefore in order to conduct this training the proper location must be available and the equipment and personnel necessary to tend to the equipment must be secured.

FARP. Establishing a FARP requires space, usually on a runway, and the training supposed to be conducted in complete darkness.[27] In practice this training is not actually conducted in

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[26] *MC-130J Ready Aircrew Program Tasking Memo (RTM)*, **Department of the Air Force Headquarters Air Force Special Operations Command. 1 Oct 2014. p.29**

[27] "Anytime we do an actual FARP it's completely lights out," said Staff Sgt. Max Horner, assistant FARP program manager. "No lights of any sort can be on - no marking lights on the helicopters or the aircraft."
**Wood, TSgt. Marelise, *"Doing it in the Dark Airmen Keep Aircraft Fueled During Multinational Exercise,"* 352nrd Special Operations Group Public Affairs, 2010.
http://www.mildenhall.af.mil/news/story.asp?id=123201209**

complete darkness because there is nowhere available that is dark enough. FARP training also requires someone to receive the fuel.

Due to the fact that many of these training events require coordination with other organizations and their chains of commands, the complexity of scheduling training is great. Many dependent factors decrease the probability of a sortie going as planned. It is common for aircrew members to mention that flights never go as planned. Even those with long careers note that they can perhaps remember one sortie that went as planned over the course of decades.

Policy Alternatives Available for Improving MC-130 Aircrew Training

Many policies govern MC-130 aircrew training and originate from various parts of the organizational hierarchy. The majority of policies come from AFSOC, the Air Force component of SOCOM.

The decisions that AFSOC makes determine the amount of funding for acquisitions related to training such as aircraft, maintenance equipment, and flight simulators. Training events for currency can be conducted in simulators up to the amount allowed by the RTM. However, the RTM allows, additional training to be conducted in simulators in order to build proficiency. Training in simulators for currency is only conducted and required if a simulator is co-located with the crew who need the training, with the exception of emergency procedure training. Aircrew members must go on TDY and travel to existing simulators if one is not available at their home duty station for emergency procedure training. Funding for more co-located simulators could increase the stability of training resources in the midst of the dynamic training environment which necessitates complex decision-making on a regular basis.

TDY training is conducted as a result of agreements with different organizations, be they joint (other U.S. military) organizations or allies. These agreements are established in advance and the training usually occurs on a regular basis. Therefore this training these events usually suffer less attrition as compared to the day-to-day training conducted at the home duty station. While these agreements are not totally within the control of AFSOC, increased use of the resources available at other locations could stabilize resources and reduce attrition.

AFSOC controls which assets they acquire, to some extent, what capabilities those assets have, and what roles they fulfill. Recently, AFSOC acquired MC-130Js. AFSOC is currently in the process of acquiring Raytheon's AN/APQ-187 which is to be installed on helicopters (MH-47G, MH-60M), the CV-22 tiltrotor aircraft, and the MC-130. "The Silent Knight Radar is the next generation Multi-Mode Radar (MMR) providing Terrain Following/Terrain Avoidance (TF/TA) capabilities. This MMR provides Special Operations Forces safe low-level flight, and safe ingress and egress in adverse environments."[28]

Coordination between the schedulers and the maintainers determines the duration and number of sorties. Shorter sorties are better for aircrew members because they require less endurance. In contrast, maintainers, the people who make sure aircraft are safe to fly, prefer longer sorties because more training is accomplished per number of planes they have to get ready to fly (and perform maintenance on after they fly). The more training events that are completed on a single sortie, the fewer sorties are needed. However more sorties provide more practice for aircrew members. While they still have to complete the same number of currency training events, according to the concept of "recency" it is better to practice for shorter durations with greater frequency in order to build experience.

Frequency and duration of sorties, having a co-located simulator, the proportion of temporary duty training, and role specialization were investigated in this research. These policies suggest areas in which policy changes might improve cost and readiness outcomes of training. The next chapter describes the approach I used to look at these policies in greater depth.

Chapter Summary

This chapter described the MC-130, discussed how aircrew continuation training works and how it is currently conducted. Next this chapter highlighted the key factors that influence MC-130 aircrew continuation training which are aircraft limitations, attrition, and resource availability.

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[28] **Johnson, Rep. Sam,** *NDAA FY15 HASC Testimony***, Committee on Armed Services, U.S. House of Representatives. http://docs.house.gov/meetings/AS/AS00/20140409/102098/HHRG-113-AS00-Wstate-J000174-20140409.pdf**

Finally, available policy alternatives for improving MC-130 aircrew training cost efficiency were identified.

Chapter 4. Methodology

To answer the research questions, I conducted a literature review and, collected information during an internship with the 353rd Special Operations Group. Based on the information gathered, I quantified an aircrew flight planning heuristic to determine feasible alternatives, created a neutral unbiased setting for analysis, developed an linear integer optimization model to select the sorties that meet currency training needs with the minimum amount of fuel, and analyzed the results of different aircrew training policies according to cost.

The Literature Review

Research on optimizing aircrew training tends to occur in times of decreasing budgets. Training is the preparation for mission readiness that is common to all parts of the military. In times of decreasing budgets, readiness becomes of particular concern because as resources decrease it is difficult to maintain the same quality and frequency of training. Because readiness is not well defined and hard to measure, this work uses aircrew currency training as a proxy measure for actual readiness.

Work in this field to date has focused primarily on initial training rather than continuation training because initial training is conducted in a prescribed and in a controlled environment, whereas continuation training and the factors that influence it vary widely. Aircrew continuation training scheduling is the process by which resources are allocated to provide ongoing aircrew member training.

In contrast to most of the research in this field, this research focuses on a cargo aircraft as opposed to a fighter aircraft. Fighter aircraft are the most populous aircraft in the Air Force, but do not compose the majority. In 2014, fighters comprised 37 percent of the Air Force aircraft

inventory. [29] Research related to the MC-130 cargo aircraft can be applied to other aircraft as well.

Most research in this field focuses on aircraft that have only one crew member, the pilot, for several reasons. The training requirements for pilots are more extensive that the requirements for other aircrew members. Also scheduling training for multi-person aircrews is comparatively more complex. This research focuses on a multi-person aircrew. Only a few studies focus on scheduling training for multi-person aircrews.

Understanding the difficulties of research in this area helped me scope the work and make decisions about constructing a model in such a way that it is useful and realistic without becoming cumbersome or intractable. The works that previously looked at multi-person aircrews were particularly useful when I was making decisions about the model. The literature I reviewed for this study is listed in Table 4.1. The table indicates the title of each article or study, whether or not the study pertained to fighter aircraft and multi-person aircrews, and the methodology the researchers used in the study.

Table 4.1. List of Articles Reviewed for This Study

Title	Fighter	Multi-person aircrew	Method
A Model-Based Optimization Plan for The Naval Helicopter Training Program [30]	No	Focuses on pilots	Supply chain model implementing formulation of linear program
A Model-Based Optimization Plan for the F-16 Pilot Training [31]	Yes	No	Linear programming model

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[29] Calculated based on inventory numbers from 2014 Air Force Almanac 2012/5434=.37

"Total Aircraft Inventory," *Air Force Almanac,* Vol. 97, No. 05, May 2014. http://www.airforcemag.com/MagazineArchive/Pages/TableOfContents.aspx?Date=05/2014

[30] **Choi, Kyujin J, and John D Sowers, *A Model-Based Optimization Plan for the Naval Helicopter Training Program*, 2011.**

[31] **Mise, Murat, *A Model-based Optimization Plan for the F-16 Pilot Training*, DTIC Document, 2007.**

A Visual Programming Methodology for Tactical Aircrew Scheduling and Other Applications[32]	Yes (A- 10)	No	Excel Visual Basic for Applications with 3-D heuristics
Combining and Analyzing the Tanker and Aircrew Scheduling Heuristics[33]	No	No, only schedules number of crews rather than individual crew members	Implements Tabu search application
Crisis Airlift Management: Effective Scheduling[34]	No	No, schedules aircraft to air fields	Queuing theory
Interactive Decision-Support System for Scheduling Fighter Pilot Training[35]	Yes	No	Excel visual basic tool
Mathematical Programming Model for Fighter Training Squadron Pilot Scheduling[36]	Yes	No	Creates weekly training schedules using mathematical programing (solves sub problems)
Models of Operational Training in Fighter Squadrons[37]	Yes	Mainly one-seat aircraft but also a two-seat optimization for the F-15E	A linear program as well as a repro model

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[32] **Dyer, Douglas E.,** *A Visual Programming Methodology for Tactical Aircrew Scheduling and Other Applications***, DEC 1991. http://www.dtic.mil/dtic/tr/fulltext/u2/a244635.pdf**

[33] **Boke, Cem,** *Combining and Analyzing the Tanker and Aircrew Scheduling Heuristics***, MAR 2003, p. 83.**

[34] **Penny, David C,** *Crisis Airlift Management Effective Scheduling***, Master's thesis, 1996. http://www.dtic.mil/get-tr-doc/pdf?AD=ADA318787**

[35] **Nguyen, Cuong T,** *An Interactive Decision Support System for Scheduling Fighter Pilot Training***, DTIC Document, 2002.**

[36] **Newlon, Thomas M,** *Mathematical Programming Model for Fighter Training Squadron Pilot Scheduling***, DTIC Document, 2007.**

[37] **Bigelow, James H, William W Taylor, S Craig Moore, and Brent Thomas,** *Models of Operational Training in Fighter Squadrons***, RAND Corporation, 2003.**

Optimizing an F-16 Squadron Weekly Pilot Schedule for the Turkish Air Force[38]	Yes	No	Greedy randomized adaptive search procedures (GRASP) using MATLAB
Optimizing Flight Schedules by an Automated Decision Support System[39]	Yes	No	Excel Visual Basic for Applications and GRASP
Optimizing Readiness and Equity In Marine Corps Aviation Training Schedules[40]	No	Yes	Bi-criteria mixed integer programing model
Robust Aircraft Squadrons Scheduling in the Face of Absenteeism[41]	Yes	Focuses on pilots	Implements optimization to find a schedule robust to absenteeism from a set of 17 schedules
Scheduling Prowler Training[42]	No	Yes, four seats	Two integer programing models
Strategic Air Command Aircrew Scheduling User's Guide[43]	No	Yes	UNIX software developed in 1991 which is not currently in use

Some studies look at scheduling for crews of various kinds, but few study aircrews. Aircrew scheduling is unique in several aspects. For one, mid-flight substitutions cannot occur unless

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[38] **Yavuz, Murat, *Optimizing an F-16 squadron weekly pilot schedule for the Turkish Air Force*, DTIC Document, 2010.**

[39] **Erdemir, Ugur, *Optimizing Flight Schedules by an Automated Decision Support System*, DTIC Document, 2014.**

[40] **Brown, Raphael P, *Optimizing Readiness and Equity in Marine Corps Aviation Training Schedules*, DTIC Document, 1995.**

[41] **Gokcen, Osman B, *Robust Aircraft Squadron Scheduling in The Face of Absenteeism*, DTIC Document, 2008.**

[42] **Raffensperger, John F, and Scott Swords, *Scheduling Prowler Training*, *Naval Research Logistics (NRL)*, Vol. 50, No. 4, 2003, p. 289-305.**

[43] **Blackwell, J. S. ; Gregorio, D. D. ; Michlowitz, E. S., *Strategic Air Command (SAC) Aircrew Scheduling Aid (SASA) User's Guide*, JUN 1992, p. 85.**

they are substitutions among people who are on the plane to begin with. Additionally, highly specialized positions restrict flexibility. Furthermore, there is a complex constraint environment dependent on many factors discussed earlier in this document such as weather, maintenance, crew availability, international agreements, geography, and the availability of training resources like drop zones, and terrain suitable for practicing low-level and other types of specialized flying. Multiple objectives such as high readiness and cost effectiveness also complicate scheduling.

This research explored aircrew training scheduling methodologies that have been applied to scheduling training for other aircrews, and looked at their applicability for scheduling continuation training for the MC-130 aircrew. The literature shows that common approaches to aircrew scheduling include linear programing, Greedy Randomized Adaptive Search Procedures (GRASP), integer programing, the use of Excel VBA tools, and Tabu searches.

The literature review provided me with a good working knowledge of this field and informed the development of the interview protocol in Appendix B. The interview protocol focused my observations during the internship on the processes of most importance.

The Internship and Information-Gathering

I served as an intern in the position of Assistant Policy Analyst for over a month at the 353rd Special Operations Group which includes two MC-130 squadrons. (Flying squadrons are units which are composed of aircraft and their aircrews.) During the internship, I gathered most of the information and data that were used in this research. Data included five-year records of training events, example training schedules, maintenance schedules and statistics, and weather patterns for all MC-130 bases. I studied documents that describe the required composition of MC-130 aircrews, observed how the aircrew training scheduling process works day to day, identified the key factors that influence the scheduling of MC-130 aircrew training, and gained insight into policy alternatives available for improving the scheduling of training.[44,45]

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[44] Originally, interviews about the aircrew scheduling process were going to be conducted as part of this research. While the study obtained the Human Subjects Protection Committee's approval and Second Level Review approval from the Air Force and met the Air Force Instruction criteria for a survey control number, the survey control office would not issue a survey control number because the Primary Investigator for this research was a student. See

Two policy documents in particular were the primary sources of data for this research.

An MC-130 policy manual explains the roles and capabilities of the aircraft. [46] The primary functions of an MC-130 are infiltration, exfiltration, helicopter air-to-air refueling, and Special Operation Forces resupply, but there are a diverse set of missions for which the aircraft can also be employed, such as search and rescue. Different roles call for different aircraft configurations or different equipment setups. For instance, a search and rescue mission would require a different aircraft configuration than an airdrop that delivered pamphlets. This document describes the different roles of the aircraft in the contexts of different missions. For example, when flying in formation with other aircraft, the MC-130 would have different roles and responsibilities depending on the mission, and would fly accordingly.

The *Ready Aircrew Program Tasking Memorandum (RTM)* stipulates training requirements for MC-130 aircrew in terms of the number of training events needed for each crew position and the frequency at which those training events should occur.[47] Training events are the individual tasks that must be accomplished for currency. The majority of training events must be accomplished on a semi-annual basis or twice a year. Many training events such as take-offs must be accomplished with greater frequency than every six months while training events such as ground training do not need to be practiced as often. The RTM specifies each of these frequencies in addition to any caveats or exceptions.

Appendix B for the interview protocol, Appendix C for the Informed Consent Document, and Appendix D for the Data Safeguarding Plan

[45] **AFSOC/A3T, "MC-130 Aircrew Training,"** *Air Force Instruction 11-2MC-130*, **Vol. 1. http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi11-2mc-130v1/afi11-2mc-130v1.pdf**

AFSOC/A3V, "MC-130 Operations Procedures," *Air Force Instruction 11-2MC-130,* **Vol. 3, 22 December 2011. http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi11-2mc-130v3/afi11-2mc-130v3.pdf**

[46] **Air Force Tactics Techniques, and Procedures 3-3.MC-130 Combat Aircraft Fundamentals. Department of the Air Force. 29 February 2012. Not publically available.**

[47] *MC-130J Ready Aircrew Program Tasking Memo (RTM)***, Department of the Air Force Headquarters Air Force Special Operations Command. 1 Oct 2014.**

Quantifying the Flight Planning Heuristic to Determine Sortie Feasibility

With the information and data I obtained during the internship, I developed a method for determining the feasibility of different flight plans for aircrew training. This method incorporated information from the *RTM* and an MC-130 policy manual. For the purpose of this research, a hypothetical location was implemented in combination with the fuel and training requirements in order to quantify the amount of fuel different flight plans require. The figure below illustrates how the information contributed to the major components of the determination of flight plan feasibility and fuel consumption. The contributions each of these components made to the model creation will be described in detail in the following sections.

Figure 4.1 Data on Training, Location, and Aircraft Limitations Determine Sortie Feasibility
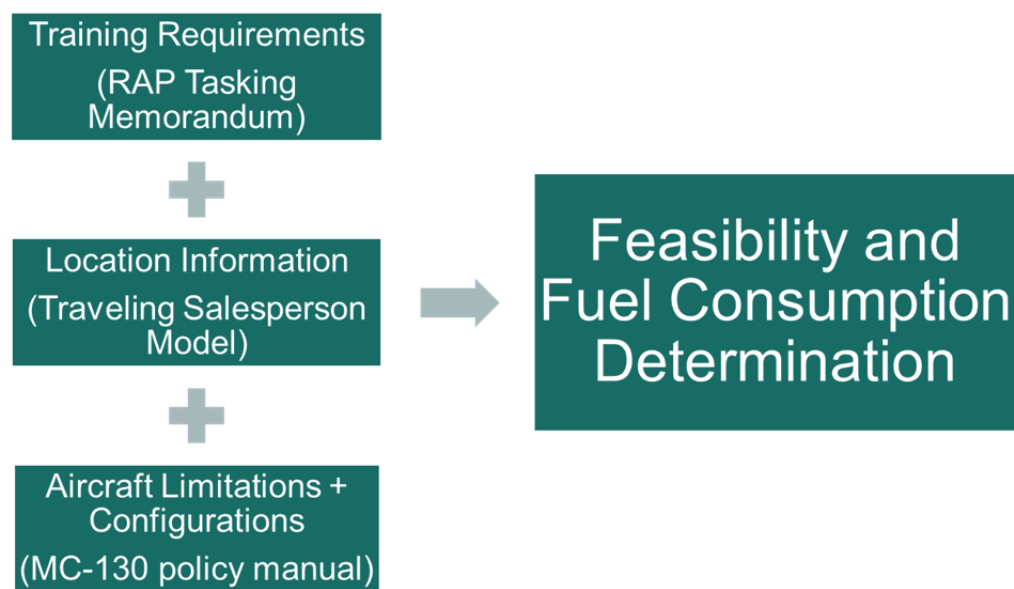
The model inputs are calculated in a spreadsheet I developed, which quantifies the flight planning heuristic implemented by aircrew members in favor of existing computerized methods. The heuristic continues to be relied on because it is faster than inputting all the sortie details into the computer each time the plan changes. This spreadsheet determines the feasibility of all the different sorties. It outputs the fuel necessary to accomplish each sortied depending on the location characteristics and fuel consumption rates of various types of flying. Additionally according to the constraints and location, the number of events accomplished on a particular sortie is calculated and input into the optimization model.

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Training Requirements

The training requirements listed in the RTM were divided into the eight categories described in Chapter 3. They are: airdrop, air-to-air refueling, helicopter and tiltrotor refueling, flying in formation, electronic warfare, low level flying, infiltration/exfiltration, and establishing a FARP . Each of these categories requires certain training resources and contributes to the overall weight of the plane, which in turn determines how much fuel is available/onboard for use in training. These categories were organized into all possible combinations, which are called "sortie sets" for the purpose of this research. A sortie set is a flight plan which includes none to all of the aircrew training categories. No training categories are mutually exclusive to one another.

Pro

Aircrew training which is designated Pro is mainly for the benefit of pilots and copilots. It is largely composed of takeoffs, approaches, and landings, which are part of every flight. Some examples of training events in this category from the RTM are Total Takeoffs, Night Takeoffs, Maximum Effort Takeoffs, Instrument Qualification Proficiency Sorties, Instrument Approaches, Circling Maneuvers, Holding Patterns, Total Landings, Night Landings, and Maximum Effort Landings. The training resources required for this type of training are airspace and runway access, which are usually available in the local area.

Airdrop

Airdrop is aircrew training which practices dropping a variety of personnel and equipment. Some examples of training events in this category from the RTM are Total Airdrop, Personnel Airdrop, and Heavy Equipment Airdrop. While there is a large assortment of things that can be dropped from this aircraft, typically for training purposes, a load of 4,000 pounds consisting of four different bundles is dropped. The training resources required for this type of training are the equipment or personnel to be dropped, the specialized rigging, and drop zone. A drop zone is a location based training resource.

Air-to-Air Refueling

Unlike most planes, the MC-130 can both distribute and receive fuel. Aerial Refueling is the operation in which fuel is received from a tanker aircraft. Some examples of training events in this category from the RTM are Total Air to Air Refueling, and Night Air to Air Refueling. For the purposes of the model it is assumed that 5,000 pounds of fuel is received when aerial refueling is included in the sortie. The training resources required for this type of training are access to the airspace where tanking is conducted and an available tanker.

Helicopter and Tiltrotor Air to Air Refueling

The MC-130 provides fuel to several types of small aircraft to support various operations. Some typical events in this training category from the RTM are Total Helicopter and Tiltrotor Air-to-air Refueling, Night Vision Goggle Helicopter Refueling, and Night Vision Goggle Tiltrotor Refueling. The training resources required for this type of training are access to the airspace where tanking occurs and available helicopters to receive fuel.

Formation

Formation aircrew training occurs when multiple aircraft fly training events together in a planned and coordinated fashion. The aircraft commander of the lead aircraft is responsible for making decisions throughout the flight. By designating roles and responsibilities, the crew of each aircraft knows how their aircraft is expected to interact with the other aircraft. Some examples of formation training events from the RTM are Formation Rejoin, Formation Airdrop, and Night Vision Goggle Formation Helicopter Air to Air Refueling. The training resources required for this type of training are the aircraft to participate in the formation, airspace to conduct maneuvers, and runway availability.

Low-Level

Low-Level or terrain-following training is basically navigating while flying very low. Flying at low levels is advantageous for other reasons such as not being detected by radar. An example of a training event for this training category from the RTM is Mountain Night Vision Goggle Low-level. The training resources required for this type of training is an available location with geography conducive to low level training.

Electronic Warfare

Electronic Warfare implements signal intelligence; i.e., sensing, interpreting, and counteracting signals to both protect the plane by avoiding problems and counter any electronic attacks such as jamming that could be used against the aircraft. Some examples of training events in this category from the RTM are Surface Radar, Airborne Intercept, and Expendable Events. The training resources required for this type of training are access to ranges and equipment that give off signals.

Infiltration and Exfiltration

Infiltration consists of training events where assets are inserted in order to accomplish a mission at a given location. Exfiltration is where assets such as people or equipment are taken out of the location. Some examples of events in this training event category from the RTM are Infiltration/Exfiltration, and Canary Slides.[48] The training resources required for this type of training are a location suitable for practicing rapid infiltration, transferring equipment or personnel to and from the aircraft and exfiltration.

Forward Area Refueling Point

FARP is used to transfer fuel from a parked MC-130 to various other aircraft or equipment on the ground. The only training event in this training category is establishing a FARP. The training resources required for this type of training are the space to set up the fuel transfer and ideally darkness. This training is typically conducted at the duty location, but the training event could be conducted anywhere the plane can land so long as the equipment is present.

Combining Categories into Sorties

In order to conduct aircrew training the training requirement categories are combined in a variety of ways into sorties. This research accounts for all the ways these categories can be combined. The calculation of the number of ways to combine the aircrew training categories on sortie sets results in 256 different combinations. See Appendix E for details. For each of these

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[48] Canary slides are specialized ramps for loading and offloading aircraft cargo.

combinations, the amount of fuel necessary and the training resources required are part of the data. The resources required for training determine the locations that must be visited to complete the training. Location and the order of training will be discussed later in this chapter.

Pilot proficiency sortie designated flights, which train takeoffs, landings, and approaches, as well as other pilot oriented training events, add one sortie set for a total of 257. But takeoffs, landings, and approaches are part of every sortie, so the remaining combinations all include pilot proficiency training events as well as some combination of the other aircrew training categories. While in the real world there are multiple ways these training requirements could be accomplished, for the purposes of the model the typical or average accomplishment rates were estimated. Additionally, when creating the training category combinations it was assumed that all the planned events would be accomplished at the training resource in one visit rather than multiple visits.

Aircraft Limitations and Configurations

In order to input all these sortie possibilities, their training resource needs, and their fuel requirements into the optimization, which minimizes the fuel required to accomplish currency requirements, a spreadsheet was created. This spreadsheet enforces many of the underlying assumptions of the model and ensures that sorties are actually feasible according to aircraft limitations. Excerpts of the spreadsheet can be found in Appendix F.

The first column in the spreadsheet ranges from 1 to 257. The numbers designate all the combinations of aircrew training categories into sortie sets. The second column of the spreadsheet is the label for each sortie set. The first part of this label is the number of categories picked by the particular sortie set. For instance, a sortie set which has only one aircrew training category is designated "Pick1" followed by an underscore and the abbreviation of the aircrew training category selected. An example is "Pick1_AD", where airdrop is the only aircrew training categories selected for the sortie set. Additionally, within this column there is the "None" sortie set where only pilot proficiency events are accomplished. The "All" sortie set contains all the categories in addition to pilot proficiency events. Where it is shorter to list the aircrew training categories not selected such as in "Pick7", the aircrew training categories not

selected are preceded by a lowercase 'n'. For example, "Pick7_nAD" is the sortie set where seven aircrew training categories are selected, all of the eight except for airdrop.

The next eight columns are composed of the eight aircrew training categories: airdrop, air-to-air refueling, helicopter and tiltrotor air to air refueling, formation, low-level, electronic warfare, infiltration/exfiltration and FARP. To indicate whether or not each of these aircrew training categories is present on a particular sortie set there is either a one or zero in the cell associated with each of the aircrew training categories for each of the 257 sortie sets.

The next column designates the total flight duration in hours. For the purposes of this research, it was assumed that, at least initially, all the sorties are six hours in length with the exception of pilot proficiency sorties which are four hours in length. These numbers are based on what actually occurs at Kadena Air Base currently. The tactical sorties usually range from five to eight hours in length. Eight-hour sorties are extreme and difficult to accomplish but are possible when necessary. It would also be unlikely that a pilot proficiency designated sortie would go longer than four hours. The Sensitivity analysis of sortie length conducted as part of this research will be discussed in Chapter 5.

The column entitled "travel duration" is a calculation of the most efficient route to get to all the resources needed to accomplish all the aircrew training categories within a given sortie set.

The training duration in the next column is the total flight duration minus the travel duration. Therefore the training duration is the amount of flying time available to conduct aircrew training.

The flight fuel weight in the next column is a calculation, in thousands of pounds of fuel, of how much fuel is needed to complete the flight. The travel time is multiplied by the rate at which fuel is typically consumed during travel and then added to the amount of training multiplied by the rate at which fuel is usually consumed during training. For the purposes of this research it was assumed that the rate at which fuel is consumed during travel is 5,000 pounds per hour and the rate at which fuel is consumed during tactical training is 6,000 pounds per hour based on a MC-130 policy manual.

The next column designates other fuel weight, which is a combination of the fuel required by training regulations to have onboard at the time of landing and any fuel needed to transfer to other aircraft.

While it is typical that when refueling helicopters and tiltrotor aircraft only 2,000 to 5,000 pounds of fuel is transferred, 5,000 pounds is used as the assumption in this case because it is the maximum amount. Since weight is used to indicate the feasibility of a sortie set, it is better to use the maximum rather than the minimum to determine if the full capacity would prevent the training from being conducted because of weight limits on the aircraft.

The maximum airdrop weight for a training flight is assumed to be 4,000 pounds based on the fact that a typical load may be one article of heavy equipment, two Container Delivery Systems (CDSs) and any number of training bundles, which are called "TBTs." While the aircraft is capable of carrying much more than 4,000 pounds, it is expensive to both drop and retrieve actual equipment and 4,000 pounds is enough weight for training purposes and more than would be typically carried, so it is a reasonable amount to work with in the model. Figure 4.2 illustrates two aircraft configurations. These images are basically floorplans of the back of the aircraft. The first shows a configuration that is primarily for personnel which are shown in pink below and some cargo shown in yellow below. The second example shows in green where pallets of heavy equipment might be placed. Feasible aircraft configurations such as those below were taken into consideration when crafting the airdrop assumptions.

Figure 4.2 Example of Two Aircraft Configurations[49]

Personnel
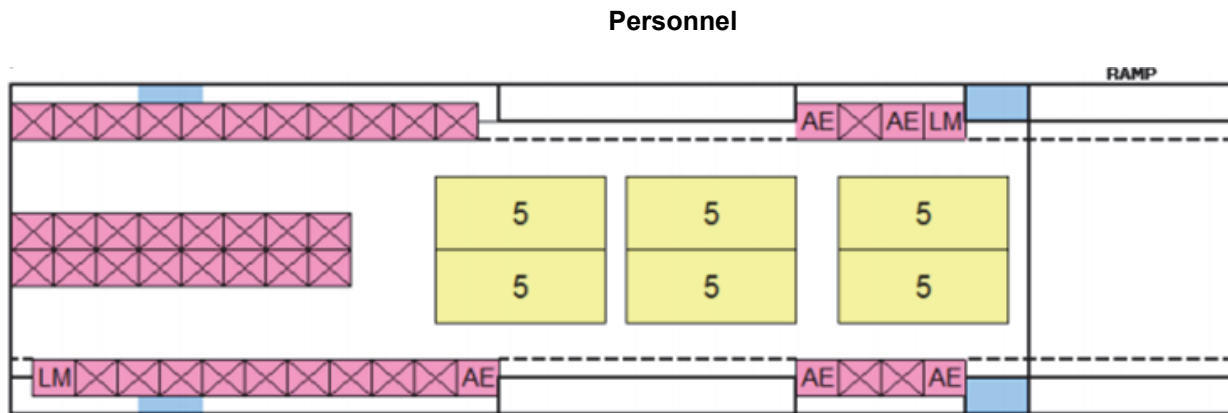
AE=Aircraft Engineer, LM=Loadmaster
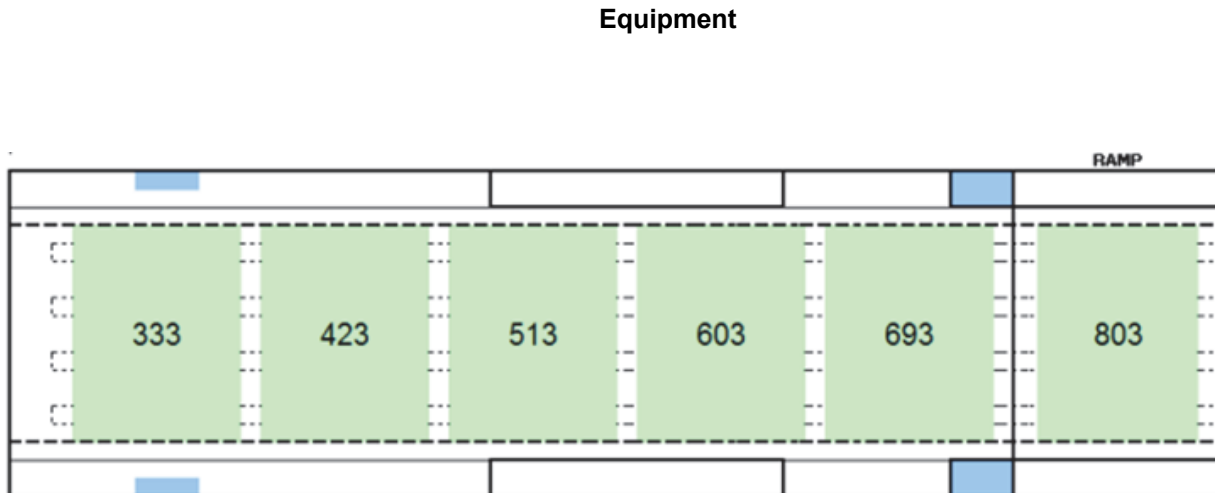
Equipment

The equipment weight column accounts for the weight of the FARP equipment. This number is rounded to 5,000 pounds for the purpose of this research. The FARP equipment accompanies the plane to the location of interest, although for training, refueling is often conducted at the home base because of resource availability. It is assumed that the FARP equipment will accompany the plane on any sortie where FARP training is included. This assumption once again seeks the

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[49] **AFSOC/A3V, "MC-130J Operation Configuration/Mission Planning,"** *Flying Operations*, **13 November 2013.**

maximum weight that could be on the plane. In reality, FARP equipment is often left at the base and this training is conducted at the base when the plane returns.

The fuel-gained column indicates whether or not the sortie set contains aerial refueling in which the MC-130 receives fuel from a tanker aircraft. The typical amount of fuel received from a tanker aircraft is 5,000 pounds.

The next column is the sum of all of these weights. The plane can weigh a maximum of 155,000 pounds at the time of takeoff for training missions. This column designates the estimated amount of weight on the plane in the form of personnel and equipment and fuel. The plane itself weighs approximately 100,000 pounds. Therefore the total takeoff weight in this column should be less than 55,000 pounds for everything at the maximum amount to be feasible on a sortie set. Sortie sets with weights exceeding this amount are highlighted in red. While this indicates they are infeasible at the maximum capacity, it is possible that the sortie sets could still be feasible with less weight.

There are certain training events that can only be accomplished when the plane is a certain weight at the time of landing. Therefore the total landing weight column indicates whether or not these training events can be accomplished at the time of landing based on the amount of fuel and equipment on the plane. The landing weight is based on the assumption that all the requirements of the sortie set are actually completed. In actuality, all the planned events may or may not be completed based on the availability of resources.

Based on the time available for training, each of the aircrew training categories within the sortie set are designated a percentage of the available time. For the purpose of this research, the training events are allotted an equal percentage of the time on the flight. Based on the time assigned to each category on a sortie set, the number of training events accomplished on a given sortie set is determined by estimating the rate at which different events can be accomplished and multiplying the rate by the allotted time. These rates were estimated to be average rates rather than either the extreme minimum or maximum.

Here are two examples of how the rates were determined.

Example 1

The number of pilot proficiency training events that can be completed in an hour is estimated to be 10 based on the fact that an aircrew proficiency sortie requires even more than 10 pilot proficiency events to be completed within an hour according to regulation. On regular flights, pilot proficiency events are likely to vary in rates. Therefore, this is an approximation of the average that is less than the maximum so as not to overestimate the number of programs completed in a given sortie. As such, sortie sets that have more categories of aircrew training have proportionally fewer pilot proficiency events on the flight and sortie sets that have fewer categories of aircrew training have proportionally more pilot proficiency events on the flight.

Example 2

Airdrop events are assumed to occur at a rate of three per hour based on the fact that it takes 20 minutes, according to regulations, to prepare a checklist to conduct the airdrop.[50] In actuality it does not necessarily take this long, but it is a good estimate of the average.

Also note that the checklist can be completed on the flight on the way to the drop zone, so the checklist is completed before the initial hour of airdrop starts, during the transit time. The initial airdrop happens at the very beginning of the hour and is followed by three more airdrops within the hour. So in the first hour, four rather than three airdrops can be completed. After the initial hour, additional hours of airdrop continue at the same rate (three per hour), but do not have the travel time advantage.

Figure 4.3 illustrates the assumption about the initial hour of airdrop. Note that this illustration only applies to the first hour of airdrop and every subsequent hour will yield only three training events.

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[50] **AFSOC/A3V, "MC-130 Operations Procedures,"** *Air Force Instruction 11-2MC-130,* **Vol. 3, 22 December 2011. http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi11-2mc-130v3/afi11-2mc-130v3.pdf p.120**

Figure 4.3 Assumptions about the First Hour of an Air Drop Training Sortie
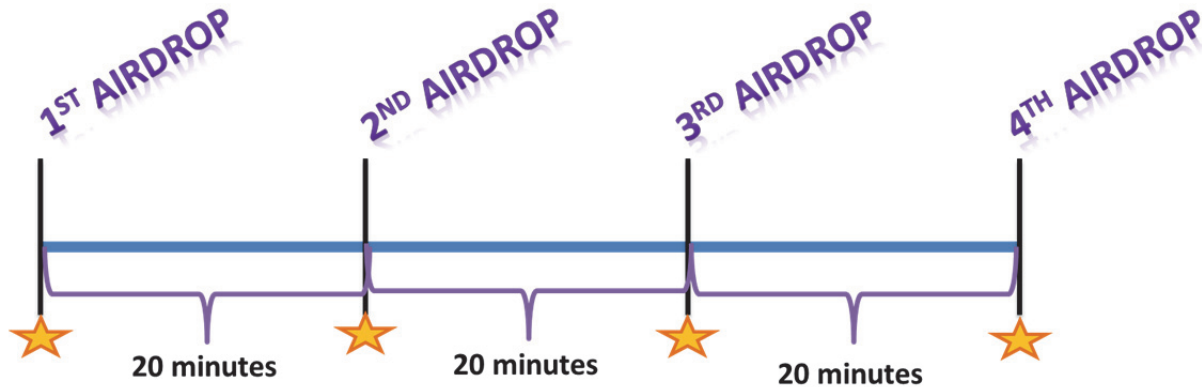
Because the estimated weight is more than typically is carried for an airdrop, it is assumed that the equipment for airdrop will not run out over the duration of the training sortie. Even though the aircraft can contain only a limited amount of heavy equipment or people, some training could still reasonably be accomplished with training bundles which simulate equipment but are essentially sandbags.

A Neutral Imaginary World

Many of the training requirements for MC-130s are reliant on training resources that are location-based. In order to create a model that is not biased by a particular location, I created an imaginary baseline map where all the resources necessary for training are half an hour away from the start point. The training resources are also half an hour from each of their adjacent resources and almost one hour from all other resources. Figure 4.4 illustrates this imaginary map. The starting location is represented by the dot in the center of the figure. The other dots represent the location-based training resources: a drop zone, tanker air space or tanker lanes for both fixed wing aircraft and helicopters, low-level geography, signal ranges, and a place to conduct infiltration and exfiltration. Training that requires a location-based training resource are only accomplished at their designated training location as shown Figure 4.5 Training Locations. Formation and FARP do not require location-based training resources. The training in these categories can be accomplished anywhere. The lines are color coded so that green represents the distance from the starting location or duty station to any of the training resources, yellow

represents the distance between any training resource locations that are not adjacent, and blue represents the distance between adjacent training resource locations.

The hexagon in Figure 4.4 illustrates the basis of this imaginary world. Note that this location can easily be adapted to any real location using the coordinates of the training resources.

Figure 4.4 Fictional Baseline Map Provides a Location-Neutral Starting Point
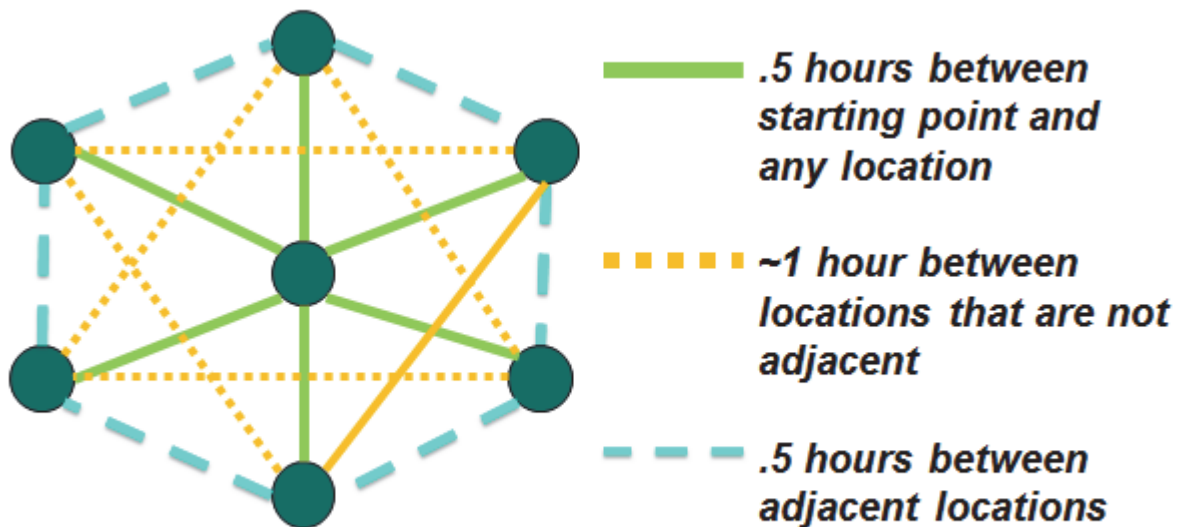
The basis of this imaginary world is a regular hexagon, which means the yellow lines are slightly less than an hour. The aircraft begins each sortie at the center.

Figure 4.5 Training Resources Locations
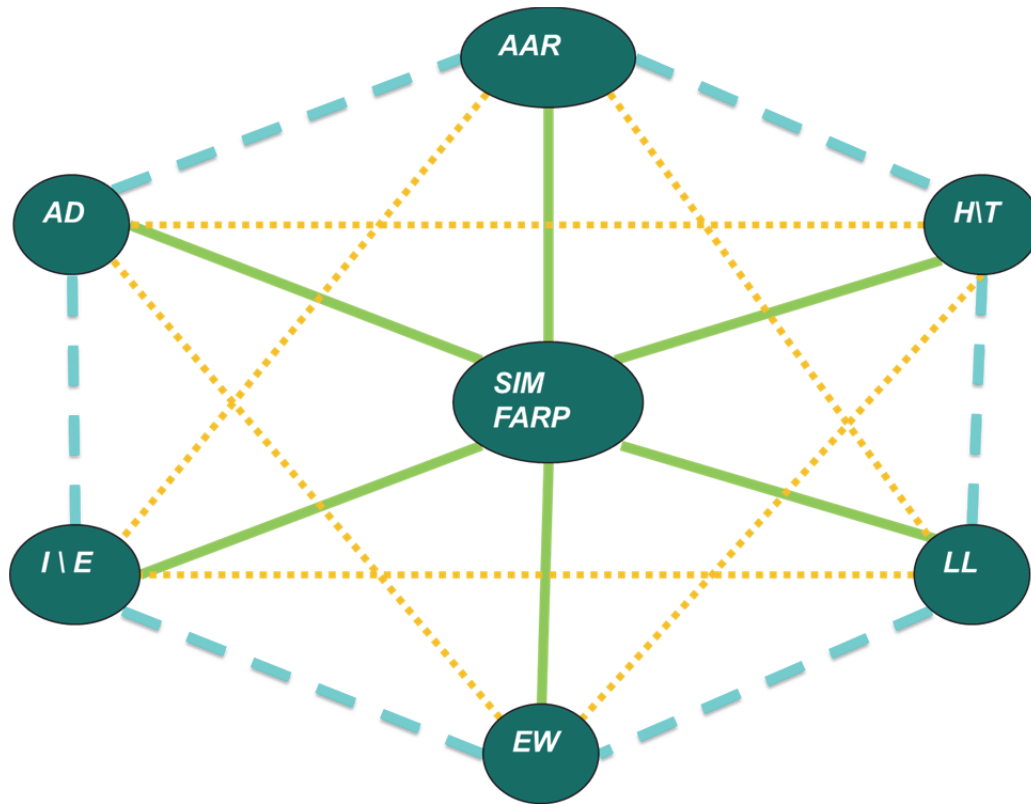
Traveling Salesperson Problem

In order to participate in training, aircrews must fly to the locations where training resources exist. There are many different ways an aircrew can fly to the training locations. In order to determine the costs of a route, the sequence of training events needs to be determined. An example of an inefficient route in the case where the aircrew planned to go to all the training resource locations would be traveling the hour-long yellow routes rather than the half-hour blue and green routes. When planning a route, people usually try to go the most advantageous way. In the case of MC-130 aircrew training, the most advantageous route is the one that minimizes travel time.

If inefficient routes were represented in the model, the model would automatically discriminate against these sorties because efficient sorties meet the goal of minimizing cost. Therefore it is

important that all the sortie combinations are represented fairly. To eliminate model bias caused by inefficient routes, the most efficient route needed to be selected for each sortie alternative. A solution for preventing this bias is to employ a classic Operations Research problem, which seeks the least cost or least distance route, known as the traveling salesperson problem.

In the most basic set up for the traveling salesperson problem, one seeks to find the shortest distance when traveling through a set of destinations, followed by returning to the origin. The traveling salesperson problem has various applications in many fields such as business, electric circuits, logistics, and robotics.[51] In this research, the following process was executed in Python, an open source programing language. Appendix G contains the Python code that was adapted for the purposed of this research. [52]

Traveling Salesperson Heuristic

1. List all the permutations of resource locations
2. Calculate the total distance for each permutation using data that associates order with the distance value
3. Compare the distances
4. Select the minimum distances
5. Select the most efficient routes
6. Output the sequence of events on the flight
7. Output the optimal route length

Repeat this process for each of the sortie category combinations. For the trivial case in which a sortie requires only one resource, calculation of the distance flown is simplified by involving only one outbound and one return leg. Due to the fact that there are seven locations, the problem becomes complicated quickly. Fortunately although the problem is complicated, it is not intractable.

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[51] **Jiang, Changbing, "A reliable solver of Euclidean traveling salesman problems with Microsoft excel add-in tools for small-size systems,"** *Journal of Software,* **Vol. 5, No. 7, 2010, p. 761-768.**

[52] **Norvig, Peter, "The Traveling Saleperson Problem."**
http://nbviewer.ipython.org/url/norvig.com/ipython/TSPv3.ipynb?utm_content=buffer7a42c&utm_medium=social&utm_source=plus.google.com&utm_campaign=buffer

There are ways to simplify the problem. Because we are only interested in beginning from the starting place and returning to that place, we do not need all the permutations. In order to compensate for this in the Python model, the code designates a starting location and then uses the permutations for the remainder of the locations to find all the ways that one can start at the starting location and return there after going to all the necessary locations. This method implements (x,y) coordinates to specify locations. Routes were selected using the TSP model and the time between sites as "distance."

The Model is a Vantage Point from Which to Make Inferences

In the real world, an algorithm does not determine the most efficient route. Human beings determine the route according to the windows of time when training resources are available. Table 4.2 illustrates the differences between scheduling in the real world, having to balance all the factors that affect it, and how training is scheduled in the "perfect" world of the model.

The differences relate especially to the dynamic scheduling environment where frequent changes occur due to unpredictable factors such as weather and as a result of imperfect data and information. The result in the real world is training that is merely what is possible given information and resources available. In contrast, the perfect world model does not have inefficiencies and selects all the right crew members for all the right training sorties to achieve currency. The real world perspective also focuses on proficiency (being proficient at the mission) rather than currency (meeting written training requirements). Being proficient at the mission is what truly matters in the real world. While the goal of currency is to achieve proficiency, doing a training event a requisite number of times does not guarantee proficiency.

While the perfect world case is obviously very different from the real world case, it provides a vantage point from which to make inferences about the real world. If a decision maker is able to justify a policy based on the absolute minimum cost of currency training in the best case scenario, then he will also be able to justify the policy in the case where training costs are higher due to real world effects.

Table 4.2. Scheduling MC-130 Continuation Training: Real World versus Perfect World

Real World	Perfect World
Minute-by-minute contingency planning because of unpredictable factors such as lack of resources, weather, maintenance delays, and last-minute changes to the flight plan	No unpredictable factors
Information overload; i.e., too much data and other information, not all of it relevant to scheduling and difficult to tease out from what is relevant	Perfect information
The training that is possible and reasonable given real-world constraints is accomplished	All the right people are scheduled on the right training sorties to achieve currency
Training is focused on proficiency	Training is focused on currency
Effective sortie route selected by human beings	Most efficient route selected by algorithm

Optimization Model

An optimization model is a mathematical model that captures key components of real-world decision making and provides a systematic, quantitative way to evaluate and select among options. I used an optimization model to analyze the efficiency of aircrew training policies based on whether they included co-located simulators and training for specialized roles and on the proportion of temporary duty assignments. While the model does not reflect real-world decision making with 100 percent accuracy, it does suggest how cost efficiency and aircrew readiness might be affected by different components of the training. For the purposes of this research, free optimization software, the GNU Linear Programing Kit (GLPK) was used. Appendix H contains a sample of the model written in GLPK.

A typical problem solved in my research consisted of 354 linear constraints and 321 variables, with each of the variables constrained to be integer valued.[53] The GLPK solver implements a primal simplex method by default, and uses branch-and-bound to deal with the integer constraints. The problem was small enough that most cases were able to converge.

Baseline Objective Function

The objective function selected minimizes the fuel needed to meet currency requirements. The function is displayed below:

$$Minimum\ Fuel\ Cost = \sum_{i=1}^{n} s[i] * f[i]$$

where s[i] are the positive integer numbers of sorties of each type accomplished and f[i] is the associated fuel used by each sortie

Many alternatives were considered for the objective function, but this was the preferred method because it provides the lower fuel cost bound.

Notably, the objective function minimizes fuel cost rather than all the costs associated with currency training. Fuel cost is a proxy for the total cost. For the MC-130J, fuel constitutes the largest portion of the flying hour cost. Fuel costs are readily available, measurable, and regularly tracked. A gallon of fuel costs the same regardless of aircraft; one must simply consider the different consumption rates. Aircrew members often plan flights in terms of the amount of fuel needed, so this is a metric that this community is comfortable thinking in terms of.

The fuel minimized by the objective function is the fuel cost for MC-130 training only, not other aircraft involved in training that have their own Flying Hour Program budgets. Including the costs of the fuel burned by other aircraft involved in training would add considerable complexity to the model, but not add much to the cost of MC-130 currency training. While these costs are an externality in terms of MC-130 currency training, they are not externalities in the wider scope of decision making.

In contrast to fuel, maintenance costs are not publicly available and are convoluted in the midst of multiple budgets. Maintenance costs for the MC-130J are understandably low as the MC-130J a new version of an existing aircraft. See Appendix A for MC-130J availability rates from Cannon AFB in September 2014. Maintenance costs also vary from aircraft to aircraft based on a variety of factors such as modifications and age of the aircraft. Additionally, maintenance costs tend to correlate with fuel costs because as the aircraft is flown more, more maintenance is

required. While maintenance costs are not included in the model they are considered in the results by comparing the fuel cost estimates to the corresponding flying hour cost estimates.

Basic Model Formulation Constraints

For the most basic version of the model, there are four main constraints. The first constraint limits the total amount of fuel. This constraint models what is called the "Flying Hour Program," which designates the amount of fuel allocated to a squadron for the purposes of aircrew training. This constraint ensures that the model does not select an alternative which uses more fuel than it is allotted. Because the model is constructed in such a way that aircrew training scheduling is conducted more efficiently in the model than it is in real life, it is unlikely that this limit would be reached since the model seeks to minimize the amount of fuel required to accomplish the RTM-required amount of crew currency training. The real-world budget currently covers currency training along with the inefficiencies of real world attrition, and all the other flying accomplished by a squadron.

$$\textbf{\textit{Flying Hour Program}}: \sum_{i=1}^{n} s[i] * f[i] \leq p$$

where s[i] are the positive number of sorties accomplished for each i sortie set, f[i] is the associated fuel used by each sortie and p is the fuel budget

The second constraint that governs the baseline model makes sure that the number of training events at least meets the number required by the RTM. For example, if a crew member is required to accomplish an event ten times over the course of the semi-annual period, this constraint ensures that the crew member at least meets the minimum requirement.

$$\textbf{\textit{Training Event Requirements}}: q[k] \leq \sum_{i=1}^{n} s[i] * r[i, k]$$

where q[k] is the number of training events required for each k training category, s[i] are the positive number of sorties accomplished for each i sortie set and r[i,k] is the number of training events in each k category associated with each i sortie set

The third constraint of the baseline model makes sure that a sortie is conducted only if the necessary resources are available. For the baseline case, all the resources are available 100 percent of the time.

$$Training\ Resources\ Available: s[i] * r[i,k] \leq x[k] * \sum_{i=1}^{n} s[i]$$

where s[i] are the positive number of sorties completed, r[i,k] is the number of training events associated with each training category k and each i sortie set, and x[k] is the percentage of time that resources for an event category k are available

Notably, r[i,k] serves two purposes. It is both the number of required training events and the number of resource packages needed to accomplish those events. The training events required are the demand and the resources available are the supply.

A fourth and crucial constraint is that the variables s[i] must be integer valued. Because the model assumes that the most efficient route is selected by the traveling salesperson algorithm and that the right person is picked for the job, it selects the minimum amount of fuel required to accomplish the minimum currency training requirements. The right person picked for the right job simply means that the person who needs a particular training event also gets scheduled for that training event. Once the baseline costs were established it was compared to the costs resulting from different aircrew training policies.

Modeling Attrition

After I obtained the results of the integer linear program, I modeled the effects of attrition using a Monte Carlo simulation. The integer linear program results are considered the perfect plan where nothing goes wrong. The key factors which influence MC-130 aircrew training are the limitations of the aircraft, attrition, and resource availability. While the regulated limitations of the aircraft are known, attrition and resource availability are unknown. Both the attrition and resource availability are dependent on seemingly infinite factors. Many of these factors are difficult if not impossible to model. For instance, while political factors definitely affect flight planning, it would be difficult to model the probability with which politics contributes to

attrition. Rather than trying to assign probability for each possibility, the general effects of attrition are modeled by assigning an attrition probability value.

Within the Monte Carlo simulation, resources for each event category are independent of each other. Within an event category, the individual events are reliant on the same resources. For each sortie selected in the perfect plan, a random number and the likelihood of attrition for each event category determines whether or not the training events planned for a sortie are completed. The number of events completed is subtracted from the total plan, and the remaining events needed are input to another integer linear program. This process is repeated until exhausted.

Each iteration is considered to be a contingency plan. Higher attrition rates result in more contingency plans. In the long term, everything approaches the attrition rates, but a semi-annual period is not long term. It is difficult to model the cost of attrition because one cannot say with certainty the point at which the contingency plan is enacted. In one case, the plan could be made before the plane takes off and all the costs could be recouped. In another case, the contingency plan could be made at the very last minute, meaning that the entire cost is forfeited. The exact cost of a single event is also hard to determine because it is dependent on many factors.

Therefore the average cost of an event for the plan generated by the integer linear program was used as the cost of an event. The cost was estimated in both the advanced planning and the last-minute planning scenarios in order to provide bounds on what the costs could be.

For example:

Yet to be completed are one air drop, three helicopter refueling events, and a formation needed to attain currency. Therefore a sortie is scheduled that combines these training categories. Each of the training categories is dependent on the availability of training resources and numerous other factors like weather. The probability of having a drop zone is 50 percent, the probability of having a helicopter to refuel and the available airspace with which to accomplish the maneuver is 50 percent, and the probability of having the aircraft and runway availability to complete a formation training event is 50 percent.

Based on random numbers, the simulation decides whether or not the resources are available to accomplish these events. In this example, everything is available except the resources for

formation training. The planning process for this training event must begin all over again. Eventually, the resources will be available and the event will be completed. Until then, each contingency plan has an associated cost even if it is just the man hours required for creating each plan and coordinating with other organizations.

Aircrew members could find out at any point in the process that resources are not available. For instance, they could find out before they start the event. In this case there is no fuel cost. Or aircrew members could find out that the resources for an event are cancelled once they are already at the location for the event. In this case, they have already expended the fuel necessary to complete the event, and incurred the associated fuel cost. The lower and upper bounds of costs establish an estimate of the range.

Cost Analysis

How the Air Force Budgets for Training

The Air Force uses the Flying Hour Model to determine the budgets for flying squadrons. Flying squadrons are units which are composed of aircraft and their aircrews. The goal of the Flying Hour Model is to ensure that all the needed training and missions are completed. The Flying Hour model does not take all events into account but looks primarily at events that have driven flying time historically. The model also accounts for the fact that not all sorties completed as planned due to unpredictable factors. The Flying Hour Model also includes funds for upgrade training for aircrew members, and maintenance of the aircraft, and accounts for typical proficiency needs. Notably, aircrew currency is not individually accounted for in the budget.

How this Research Does Cost Analysis

This research took the outputs of the optimization and calculated the costs of currency training in the different scenarios two ways. First, the number of flight hours is multiplied by the Air Force-assigned flight hour cost.[54] Second, the number of gallons of fuel burned is multiplied by the cost

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[54] $4,962 FY14

AFI 65-503, Table 15-1, Aircraft Reimbursement Rates.2014.

of fuel.[55] This allows different policies to be compared on the basis of training events completed per gallon of fuel burned.

Chapter Summary

This chapter described the methodology of the dissertation. First it goes over how the literature review contributed to the knowledge needed to observe during the internship in an educated manner and construct the integer linear optimization model, which minimizes the fuel necessary to complete currency training. Next, the chapter described how the information gathered in the internship contributed to the construction of the integer linear optimization model and was used to determine feasible model inputs. Then the fictional baseline map which provides a location neutral starting point was described in detail along with the traveling salesperson model used to select the most efficient routes for sorties. The integer linear optimization model itself was then described. Next, the attrition simulation analysis was discussed and finally, the cost analysis was discussed.

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[55] $3.7 FY14
AFI 65-503, Table 15-1, Aircraft Reimbursement Rates.2014.

Chapter 5. Results Section

The chapter describes the results of the policy analysis. Data associated with each of the policies will be presented in turn. First I discuss the baseline case, which is used as a comparison point for all the other policies. Next I will discuss the implications of having a co-located aircraft simulator, how I modeled this policy, and the results of the analysis. The policy that allows members to go TDY to more favorable training locations will be discussed in terms of its advantages and disadvantages. The unique aspects of the TDY assignment model will be discussed along with the results of the analysis of this policy. Next, the role specialization policy is explained, followed by how this policy was modeled and the results of the analysis. The effects of these policies will be compared and contrasted. Finally the implications of attrition for these policies are discussed.

Baseline Case

The baseline case for the model is a case where the training resources are all a half an hour away from the starting location, the duty station. The number of crew members in the squadron in the model, were selected so that they were similar to actual.[56] The duration of sorties in the baseline case is four hours for pilot proficiency sorties and six hours for everything else. The model is based on the semi-annual period but the time period displayed below is a year, or two semi-annual periods. Table 5.0.1 shows the flight hours, the gallons of gas, and dollar costs in terms of MC-130J flight hours ($4,962/hour).[57] Recall that this is the minimum fuel required to complete minimum currency requirements using feasible sortie inputs, in a perfect world without any unpredictable factors.

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[56] but also intentionally made not exactly alike.

[57] **AFI 65-503, Table 15-1, Aircraft Reimbursement Rates. 2014.**

When interpreting these numbers, it is also important to realize that semi-annual training does not take a full six full months to complete because only a fraction of time is available for flying. Aircrew members have a number of responsibilities in addition to maintaining currency, achieving proficiency, and conducting missions. They also must conduct ground training, ancillary training, execute the duties of their "desk job" and numerous other things such as volunteering to organize squadron morale functions.

Table 5.0.1 Baseline Case Results of Analysis[58]

Flight Hours	Flying Hours Cost ($FY15)	Pounds of Fuel	Fuel Cost (at $3.7/gallon)
1024	$5.1M	6,022,000	$3.3M

Recall that the cost per flying hour from AFI 65-503 includes fuel, depot level reparables, depot maintenance, and other costs. Since the fuel cost takes up the majority of the flying hour cost above, is can be seen that maintenance cost per flying hour estimates for new MC-130J are low.

Many different selections could have been made for the baseline case. The following sensitivity analyses describe how the results would change if different decisions had been made for the baseline case.

Analysis of the Duration and Frequency of Sorties

As sortie duration decreases, currency training costs more because individual sorties yield fewer events and more travel costs are incurred. Maintenance costs also increase as the frequency of flights increases because each flight requires maintenance before and after the flight.

While it cannot easily be quantified into dollar terms, there is some value in training on a more frequent basis, particularly for less experienced aircrew members. A co-pilot who flies twice a week is better off than a co-pilot who flies once a week even if the two pilots fly the same amount of time and do the same training events simply because the one who flew twice had two

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[58] Fuel weight is 6.79 pounds per gallon

opportunities to lay neural pathways. [59] This example illustrates the concept of "recency" in learning and skill acquisition. In the same way, studies show that a person learning a new language is better off practicing a little time every day than studying longer but less frequently. The value of recency varies with experience levels. Take, for instance, a teenager learning to drive versus an experienced driver. Initially more practice starting the engine, backing down the driveway, making turns, and parking is advantageous. Eventually, these tasks become habitual and intuitive.

The following shows the cost of continuation training in the case of four, five, and six hours sorties.[60] The six hour case is the baseline model.

Table 5.0.2 Sortie Duration and Frequency Results

	Baseline (6 hour sorties)	5 hour sorties	4 hour sorties
Flight Hours	1024	1184	1436
Flying Hours Cost ($FY15)	$5.1M	$5.5M	$6.7M
Pounds of Fuel	6,022,000	6,953,268	8,410,411
Fuel Cost (at $3.7/gallon)	$3.3M	$3.8M	$4.6M
Number of Sorties	196	226	270
Cost Increase	(N/A)	$0.4M	$1.6M

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[59] When learning new things, memory and recall are strengthened by frequency and recency. The more we practice and rehearse something new and the more recently we have practiced, the easier it is for our brain to transmit these experiences efficiently and store them for ready access later. This process is called fluency.
Donald J. Ford Ph.D., C.P.T., "How the Brain Learns," July 20 2011.
https://www.trainingindustry.com/content-development/articles/how-the-brain-learns.aspx

[60] "Pro" sorties are 4 hours long in all cases

The Baseline case is cheapest in terms of fuel and flight hours without even considering the additional maintenance costs this policy would incur. More time is spent traveling for more frequent, shorter flights. When considering the costs of the maintenance component, which in the table above is a fixed component of the flying hour program, it is important to realize that the maintenance costs will grow more rapidly both as a result of flying a greater number of sorties as well as flying longer. Having a greater number of sorties means more hours spent on the routine maintenance tasks that occur before and after flight. Flying the additional hours means that the aircraft will have more wear and tear that will result in more maintenance needs.

Analysis of Crew Composition

With multi-person crews, the crew member who needs the most sorties determines the number of sorties needed for the whole crew. The Air Force recognizes this and uses it as an assumption in AFI 11-102, "The crew position that drives the greatest number of flying hours is the total requirement."[61] Changes in crew composition only affect the number of sorties needed so long as they affect the maximum training needed for a given crew member. Increasing a population, in such a way that it becomes the new maximum causes an increase in training needs. Conversely, decreasing a population so that it is no longer the maximum or a lesser maximum would decrease the overall training needs of the squadron.

The crew members that are most likely to affect the maximum are the ones with the most events. In this case, the pilots and co-pilots of C-experience level, which is the lowest possible experience level, tend to affect the amount of training needed to the greatest degree.

According to a news report at RAF Mildenhall AFB this year, the size of MC-130 squadrons will be increasing in terms of personnel in the future.[62] If the squadron size were to increase in a manner where new maximums for training needs were reached, the cost of continuation training

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[61] **AF/A3O-AT, *Air Force Instruction 11-102 Flying Hour Program Management*, Operations, Flying, Secretary of the Air Force, 2002. p.4**

[62] **Turner, Terry, "Video: Special Ops Group Upgrades Aircraft," DoD News, 2013. https://www.dvidshub.net/video/296148/special-ops-group-upgrades-aircraft#.VfBEq9JVikp**

would increase. This relationship is displayed in Figure 5.0.3 below where a case with a crew size increased by 18 percent is compared to the baseline case.

Table 5.0.3 Crew Composition Results

	Baseline	Baseline with larger crew
Flight Hours	1024	2012
Flying Hours Cost ($FY15)	$5.1M	$9.4M
Pounds of Fuel	6,022,000	11,833,411
Fuel Cost (at $3.7/gallon)	$3.3M	$6.4M
Number of Sorties	196	390
Cost Increase	(N/A)	$4.3M

Analysis of Changing the Rates of Fuel Consumption

As newer aircraft platforms are developed, the rates of fuel consumption tend to decrease. This is the case with the MC-130J. The following table shows how the baseline model would be affected if the fuel consumption rate assumptions were to decrease 8 percent for travel and 16 percent for tactical training.

Table 5.0.4 Sortie Decreasing Fuel Consumption

	Baseline	Baseline lower fuel consumption
Flight Hours	1024	1024
Flying Hours Cost ($FY15)	$5.1M	$5.1M
Pounds of Fuel	6,022,000	5,071,200
Fuel Cost (at $3.7/gallon)	$3.3M	$2.8M
Number of Sorties	196	196
Savings in Fuel	(N/A)	$0.5M

As seems logical, better fuel efficiency results in savings. Notably, the flying hours cost estimate does not change because it is based on a flying hour cost of $4,962 FY14 an hour and does not account for changes in fuel efficiency.[63] In reality the flying hour cost changes over time with updated estimates based on historical usage rates.

Increasing the Distance of All Training Resources Increases the Cost of Currency

Service members are assigned to work at various bases. A service member's base is considered their primary duty station. Aircrew members tend to conduct the majority of their continuation training at their primary duty station.

When all of the training resources are located at the duty station, training is cheapest because the aircraft and aircrew do not have to travel to other resource locations for training. As the distances of training resources collectively increase, the cost of currency training also increases. When looking at all the training resources distances increasing at the same time, the distances cannot go beyond a certain point without some of the sortie combinations becoming infeasible.

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[63] **AFI 65-503, Table 15-1, Aircraft Reimbursement Rates. 2014.**

Table 5.0.5 Increase All Training Resource Distances

	0 hours	.25 hours	Baseline (0.5 hours)	.75 hours
Flight Hours	888	948	1024	1088
Flying Hours Cost ($FY15)	$4.4M	$4.7M	$5.1M	$5.4M
Pounds of Fuel	5,328,000	5,626,500	6,022,000	6,333,000
Fuel Cost (at $3.7/gallon)	$2.9M	$3.1M	$3.3M	$3.5M
Number of Sorties	188	192	196	208
Change in Cost From Baseline	-$0.7M	-$0.4M	(N/A)	+$0.3M

Increasing the Distance of Single Training Resources Increases the Cost of Currency Training

Starting with the baseline case, I also looked at the effect of increasing the distances of individual training resources. It is apparent that some training categories are more sensitive to distance increases than others. This is demonstrated in Figure 5.1 below which shows the added currency flight hours per year relative to the baseline case. When the helicopter and tiltrotor training resource is two hours away, currency training requires over 300 more flight hours that when the helicopter and tiltrotor training resource is half an hour away. Notably, the resources with lower supply-to-demand ratios incur costs more quickly as the distance of the training resource increases.

Figure 5.1 Increasing Individual Training Resource Distances
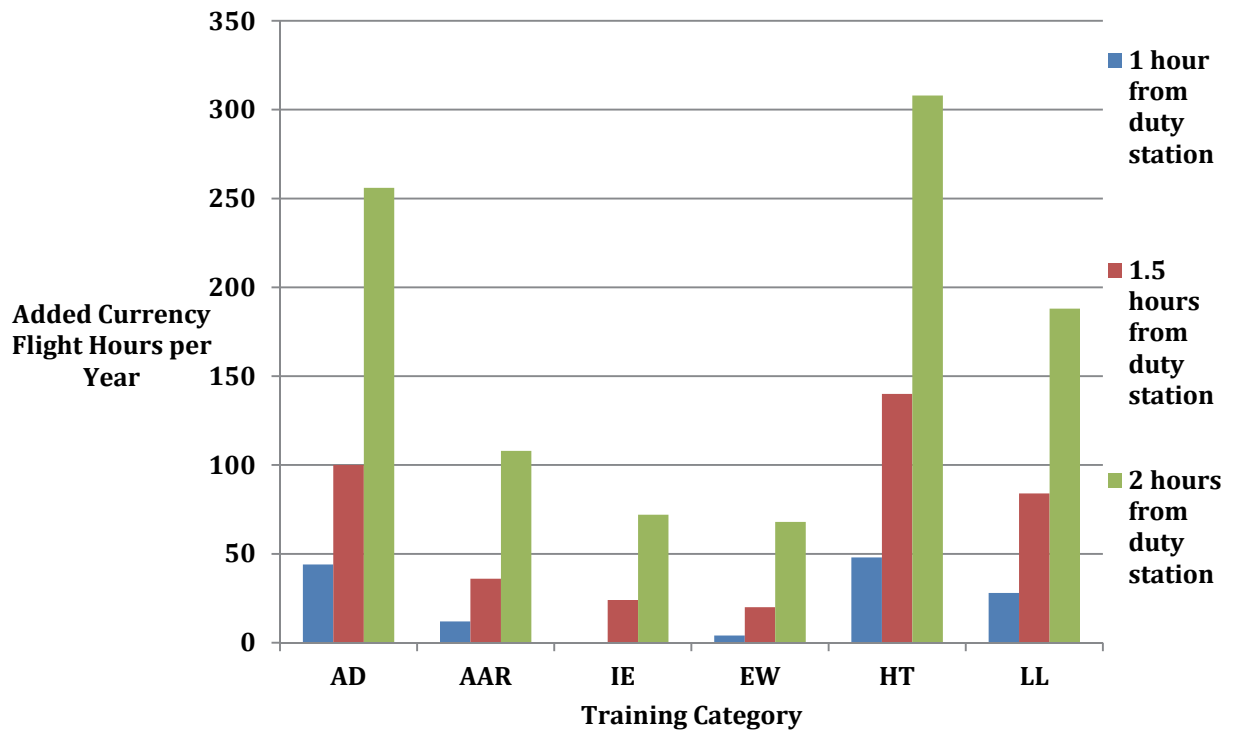
Flight Simulators in Training

Background on Simulators

An aircraft simulator is a training device that replicates actual flight**.** Commercial airlines have used aircraft simulators for many years to enhance training and reduce costs. According to one study, "In the mid-80s the airline industry had concluded that simulators had enough capabilities to enable them to conduct a majority of their training in a simulator."[64]

Commercial flying is fundamentally different from military flying, though some commonalities exist. In fact, many military pilots become commercial pilots upon retirement. Military flying is generally more complicated and risky than commercial flying, but commercial pilots tend to be more experienced. After initial training, military pilots have approximately 220- 250 flying hours whereas new commercial pilots (first officers) are required to have 1,500 flying with a few

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[64] **Thomas, Mark A,** *The Benefits of Simulator Integration to AMC***, DTIC Document, 1999. p.11.**

exceptions. [65,66] Notably, a military pilot can become a first officer commercial pilot with only 750 hours of military flying hours. Due to the unique and demanding nature of military flying, standards for flight simulator training are higher than those in the commercial world.[67] As a result of the higher standards, simulator integration has occurred in the military to a lesser degree. The majority of military continuation training is still conducted in the aircraft.

Different types of simulators are used for MC-130 training. The type discussed in here is an aircrew simulator, where the crew gets to practice flying in what is basically a giant moving box with a model cockpit inside including big screens that display the "flight." However, the entire crew is not trained in this type of simulator. The loadmasters are not included. Currently at Kadena Air Base, there are two types of loadmaster simulators but neither type is as technologically advanced as the one that is being discussed in this research for the rest of the aircrew. Ideally, at some point, the simulators can be connected so the whole crew can practice as a crew and consequently build unit cohesiveness.

Flight simulators have many advantages. A single flight hour in a simulator is much more economical than a flight hour in an aircraft. Utilizing an aircraft simulator spares the cost of the travel for substituted training events. Compared to actual aircraft, aircraft simulators are less affected by real-world factors such as weather, maintenance problems, injury and illnesses of aircrew members, and the availability of training resources.

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[65] **"JSUPT - USAF Military Pilot Training Information." Baseops. http://www.baseops.net/militarypilot/**

[66] "The rule requires first officers — also known as co-pilots — to hold an Airline Transport Pilot (ATP) certificate, requiring 1,500 hours total time as a pilot."
**Dorr, Les, Jr. "Press Release – FAA Boosts Aviation Safety with New Pilot Qualification Standards." Federal Aviation Administration.10 July 2013.
https://www.faa.gov/news/press_releases/news_story.cfm?newsId=14838**

[67] "These simulators, like many other military simulators for heavy aircraft, are effectively to a "Level D plus" standard, the plus features (over airliner training requirements) being the military additions such as Air Refuelling, formation flying, STOL operations and low-level air load dropping."
"Military Flight Simulators Today," Defence, 2010. http://halldale.com/insidesnt/military-flight-simulators-today#.VfstfdJVikp

Aircrew members who have serious conditions that temporarily prevent them from flying can even maintain currency to some extent in the aircraft simulator. Because there is reduced dependence on assets controlled by other agencies less time is devoted to planning and re-planning training sorties as conditions change.

Additionally, in the simulator aircrew members can practice training events that are impossible to simulate in real life, such as emergency procedures. Usually crew members go on a temporary duty assignment to practice emergency procedures at an existing simulator, if they do not have a co-located simulator. Having a co-located simulator available for practicing emergency procedures is advantageous for attaining proficiency in these important skills.

Furthermore, whereas in the actual aircraft, it is more costly to increase recency by conducting training more frequently, in a simulator it is more cost effective to do so. An aircraft simulator can also be used to conduct cost-of-business sorties such as aircrew member upgrades (training which prepares aircrew members for new skill qualifications).

Flying hours conducted in an aircraft simulator spare the actual aircraft from the wear and tear of flight. Using an aircraft simulator increases the service life of planes, decreases the demands on maintenance personnel and reduces the need for spare parts.

Aircrew members also benefit from simulators because time previously dedicated to contingency planning or traveling to resource locations can be invested in their personal lives and/or time with family.

In the future, aircraft simulators will hopefully incorporate what is called Distributed Mission Operations, which integrates simulators all over the world with actual aircraft, aircrew, and satellites. Today it is common for video gamers from all over the world to connect for playing games; however, as of yet there is only limited connection among aircraft simulators.

Much like the skills and teamwork building that occurs when working together on a video game, it would be useful for aircrew members to be able to practice working together from simulators that are not co-located. Furthermore the more real-time data that can be integrated into the training process the better the training becomes. This research only discusses simulators without Distributed Mission Operations technology. However it is important to realize that having

simulators in use and in place would be advantageous for laying the groundwork for this kind of technology in the future.

Contrastingly, aircraft simulators have many disadvantages. The initial cost of an aircraft simulator is a large and not only must it be purchased, transporting and installing the aircraft simulator is expensive. Furthermore ongoing maintenance costs are associated with aircraft simulators. While aircraft simulators reduce the planning burden, they also reduce the interactions with other organizations, which are important for accomplishing the mission. Aircrew members also have less time in the actual aircraft when an aircraft simulator is present. Training with the aircraft simulator reduces the fog and friction in the training experience. The environment is controlled, meaning that there are less psychological pressures. In contrast to flying the airplane, with simulators aircrew members know that they are going to walk away from simulator even if a mistake occurs. Additionally aircrew members' bodies do not experience the physiological impacts of actual flight in an aircraft simulator. Maintainers also get less experience in maintaining the aircraft once an aircraft simulator is present.

While the simulator is less vulnerable to weather concerns than the aircraft, there is still an impact to operations when lightning within 5 nautical miles or flooding occurs. The simulator can still run in the lightning scenario, but it must 'come off motion'; meaning the motion system must be turned-off, to prevent being stuck at an inaccessible angle, in case the building loses power. The offline motion system detracts from the realism of training during this time.

Additionally, the simulator possesses its own set of maintenance issues. While simulator maintenance attrition is less common than aircraft maintenance attrition, training is occasionally lost due to the simulator being down.

The current aircraft simulator does not meet the accuracy requirements to log all training events. Only training events designated in the RTM count towards training requirements.

Having a co-located aircraft simulator does not mean that it is utilized to the fullest potential. The generally accepted perspective is that aircrew members prefer training in the actual aircraft. Therefore, the installation of a co-located simulator might result in utilization rates where savings generated by the simulator accrue slowly.

The fact that willingness to accept aircraft simulators remains a topic of major discussion and consideration in the military suggests that the acquisition and utilization of simulators is not a business decision in the same way that it is for commercial airlines. By making the implementation of simulators a business decision to a greater degree rather than a cultural decision, the cost efficiency of currency training can be improved.[68] A business decision ought to take into consideration the costs associated with the function, availability, and distance of training resources.

Methodology for the Analysis of Simulators

For the purposes of this research three simulator conditions were modeled: baseline, must, and can. Baseline is the same neutral situation as before, where all training resources are half an hour away from the starting point and there is no simulator.

Once a co-located simulator is present at a duty station, aircrew members are required to complete certain training requirements in the aircraft simulator as designated by the RTM. Must is the same as Baseline except there is a co-located simulator present at the duty station. In this case, the minimal aircraft simulator requirements are completed according to regulation.

Can is the same as the baseline case except that a co-located simulator is employed to the full extent, meaning that all the events which can be substituted out of the aircraft are done in the simulator. A co-located simulator could also be implemented beyond what is allowed to be substituted for currency training, to increase proficiency and for use in cost of business sorties that do not contribute to currency training. This research only models the substitutions pertaining to currency.

Just like in the aircraft, certain individual simulator training events can count towards the currency training requirement for multiple events. For example, in the plane a night-landing event counts towards the night landing currency requirement as well as the total landing requirement. In the simulator a night-landing event counts towards the aircraft landing, aircraft

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[68] Military decisions cannot be wholly unpolitical even if they are made on the basis of costs. For instance, one cannot put a price on nuclear deterrence.

night landing, and simulator landing requirements. As shown below, the combination of aircraft and simulator events meet the total event requirement.

$$q[k] \leq (s[aircraft\ sortie] * r[aircraft\ sortie, k]) + (s[sim\ sortie] * r[sim\ sortie, k])$$

where q[k] is the number of training events required for each k training category, s[i] are the positive number of sorties accomplished for each i sortie set and r[i,k] is the number of training events in each k category associated with each i sortie set

The model requires the required amount of simulator training events that come with having a co-located simulator. After filling the requirement, the model then substitutes up to the amount allowed by the RTM in order to select the amount of simulator events that can substitute for in flight training. The substitutions allowed constraint ensures simulator substitutions do not exceed the amount allowed by regulation.

$$\textbf{Substitutions Allowed}: \sum_{i=1}^{n} s[i] * r[i, k] * g[i] \leq a[k]$$

where s[i] are the positive number of sorties accomplished for each i sortie set, r[i,k] is the number of training events in each k category associated with each i sortie set, g[i] is an indicator or whether sortie is conducted in the simulator, and a[k] is the number of simulator events that can be substituted into the flight simulator for training event category k.

The following are examples of how the substitutions were decided for the model. Figure 5.1.1 is an example of a substitution where the simulator training event SAP30 can only be substituted for one regular event requirement in the aircraft, AP30. Say the required frequency for AP30 in the training period is three, and the required frequency for SAP30 in the training period is one, only if the simulator is co-located. The RTM specifies the number of AP30 events that must occur in the aircraft.

If the number of events that must be conducted in the aircraft is three, then three AP30 events will be accomplished and one SAP30 event will be accomplished. If the amount that must be accomplished in the aircraft is two, then two AP30 events will be accomplished and one SAP30 event will be accomplished, satisfying both requirements. If the amount that must be accomplished in the aircraft is one, then one AP30 event will be accomplished and two SAP30 events will be accomplished. If the amount that must be accomplished in the aircraft is zero, then zero AP30 events will be accomplished and three SAP30 events will be accomplished.

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Figure 5.1.1 Example 1 of Substitution

$$AP30 \longleftarrow \overset{only}{\quad} SAP30$$

Table 5.1.1 Example 1 of Substitution

Number Required to Occur in Aircraft	AP30 (3 training events required total)	SAP30 (1 training event required total)	Number SAP30 Substituted for AP30
3	3	1	0
2	2	1	1
1	1	2	2
0	0	3	3

Figure 5.1.1 illustrates a simple case of substitution. The complexity increases as multiple simulator events can be substituted for multiple in-aircraft training events resulting in some overlap. In these cases, multiple ways to make substitutions are possible. Some simulator events can substitute for up to seven training events in the aircraft. The following Figure 5.1.2 shows an example of where a simulator event can substitute for two training events in the aircraft. This chart is set up similarly to the one above.

First note that where it is possible to substitute two different simulator events for one in-aircraft event, a simulator event can be counted twice towards the total training requirements. An example of this occurring can be seen in the row below with a yellow highlighted box. In this case, SAP71 is counted both towards the AP80 and AP71 requirements. This practice is called "dual-logging" by aircrew members.

Secondly, note that for modeling purposes, when given a choice, the simulator training event that counts for the most events will be preferred. This type of substitution is illustrated in the last row with the pink highlighted box in the fourth column. This strategy is something observable in the real world. Aircrew members try to get the most out of their training time. For instance, because a night landing training event counts both towards landing and night landing training requirements, aircrew members try to maximize their night landings.

Figure 5.1.2 Example 2 of Substitution
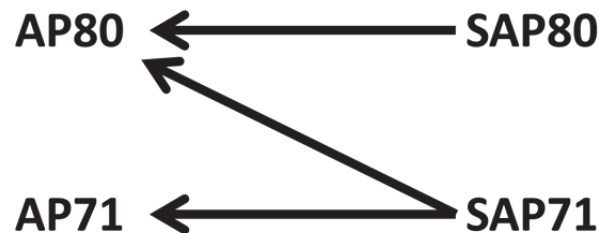
Table 5.1.2 Example 2 of Substitution

Number Required to Occur in Aircraft (*3 total training events required for each event)		SAP80 (1 training event required total) SAP71 (1 training event required)		Number Substituted For AP80		Number Substituted For AP71	
AP80	AP70	SAP80	SAP71	SAP80	SAP71	SAP80	SAP71
3	3	1	1	0	0	0	0
2	3	1	1	0	1	0	0
1	3	1	1	1	1	0	0
2	2	1	1	1	0	0	1
1	1	1	2	1	1	0	2

While this strategy exists, it is important to understand that it likely would not be employed as universally as it is in the model. The goal for this substitution strategy is not for aircrew members to make decisions in this manner, but to ensure that the model is making simulator substitutions in a predictable unbiased way, according to the regulations set out by the RTM . In the real world, it is not ideal for an aircrew member to try to do the least training possible to meet currency requirements. With the goal of proficiency in mind it would be better to complete as much training as is needed and possible. From a cost analysis perspective, however, it is better if the minimum amounts of simulator substitutions are made so that potential savings are not inflated by inefficiencies inherent in the model.

By regulation, not all events can be substituted into the aircraft simulator. Because not all training events can be accomplished in the simulator, only applicable training categories were included in the possible sorties in the model. The same method as was used for the aircraft sortie possibilities was implemented for determining all the sorties training category combinations that can be conducted in the simulator. Simulator sorties were assumed to be four hours in duration.

Costs of a Simulator

A simulator is a very expensive piece of equipment. When considering the cost of a simulator, however, one must consider not only the cost of the equipment itself but all the costs related to it. To have a co-located simulator, one that is located at the duty station, one must be transported and installed. The simulator requires a certain environment to be maintained in order to operate properly. Operating the simulator also has some costs associated with it. The life of a simulator is not unlimited; wear and tear from use incurs costs over time. Additionally, in order to operate a simulator, certain resources which accumulate costs are needed, such as electricity and staff people. For the purposes of this research, the initial cost of the simulator equipment, transportation and installation is $30 million.[69] Ongoing costs of operation are estimated to be covered by $500 per hour of use.[70]

For a simulator to justify its acquisition and placement, it needs to generate savings in a reasonable amount of time. The U.S. military does not have a set amount of time or set method for justifying the acquisition of a simulator. One common method is to look at savings in terms of flight hours.

Costs of an Aircraft

Fluctuations in the cost of flying the MC-130 can change this cost analysis drastically. Aircraft have a number of costs associated with them. There is the cost of developing the aircraft (Research and Development, or R&D cost). Once an aircraft is developed it needs to be produced, first in prototypes for testing, then in the quantities needed for use (Investment cost).

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[69] MC-130J simulators are bought on the AMC contract and cost about $25M according to Craig Vara former Chief of Aircrew Management at AMC.

[70] "typical simulators can operate around $500 an hour" The Benefits of Simulator Integration to AMC p. 13

Once the aircraft are produced, aircrew and maintenance personnel need to be trained in how to operate and maintain them (Operations and Maintenance, or O&M cost). The aircraft also need to be distributed in the places where they are most useful along with the necessary maintenance equipment and spare parts. Over time, modifications and upgrades are usually made to the aircraft and it must travel back to the manufacturer or a maintenance depot. This is also the case for major repairs. General repairs and maintenance are accomplished at the duty station on an ongoing basis. Due to wear and tear from use, the costs of maintenance and repairs are incurred more rapidly over time. All things considered, the cost of an aircraft increases over time. Inflation and variable fuel costs increase the cost of flying the aircraft over time.

The acquisition of the MC-130 has been unique. The "slick" or basic aircraft was a commercial off the shelf (COTS) product of Lockheed Martin, which was then modified for the purposes of AFSOC. Acquiring the aircraft as a COTS product tends to reduce the acquisition cost and complexity.

The Flying Hour Program only accounts for some of the costs mentioned above. The cost of a flying hour is composed of a historical estimate of only fuel costs, depot level reparable costs, depot maintenance costs, and consumables required costs.[71] The formula below describes this estimate.

Figure 5.1.3 Single Flying Hour Cost Formula

$$Flying\ Hour\ Cost = \frac{Fuel\ Cost + Maintenance\ Cost + Consumables\ Required\ Cost}{Total\ hours}$$

Ideally the best way to do this cost analysis would be to compute the life cycle costs of the fleet of aircraft with and without co-located simulator use in the context of all the simulator costs mentioned above. However, funding over the life cycle of the fleet comes from a variety of different funding streams, some associated with the service and some with other parts of the government. Also, some of the financial information needed for a life cycle cost estimate is not publicly available. Because of these complexities, I compare the cost of acquiring and operating

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[71] **DoD Financial Management Regulation Volume 11A, Chapter 6, Appendix E**

a simulator with the cost of fuel and the flying hour cost associated with the aircraft. A key limitation of this is that the flying hour cost does not include all the costs of the aircraft discussed above. However, it should be noted that research and development costs, operation and maintenance personnel costs, and investment costs do not vary in the policies examined in this research. Therefore, selecting the flying hour cost as a metric is reasonable because it captures the changes from one policy to another.

A Co-located Simulator Becomes Increasingly Valuable as the Cost of Training Increases

It is evident that having a co-located simulator reduces the cost of training. The cost of training is reduced even when the co-located simulator is not utilized as much is allowed by the RTM. It is quite possible that the simulator could be utilized to a greater extent than mandated by the RTM and potentially save money which could then be spent towards attaining proficiency.

As shown by the chart below, a simulator can save between $420,000 and $980,000 per MC-130J squadron, per year, and the savings increase in situations where training resources are located farther from the duty station. Figure 5.1.4 looks at currency training in terms of fuel savings.

Figure 5.1.4 Simulator Fuel Cost Savings for MC-130J as Distances to Training Resources Increase
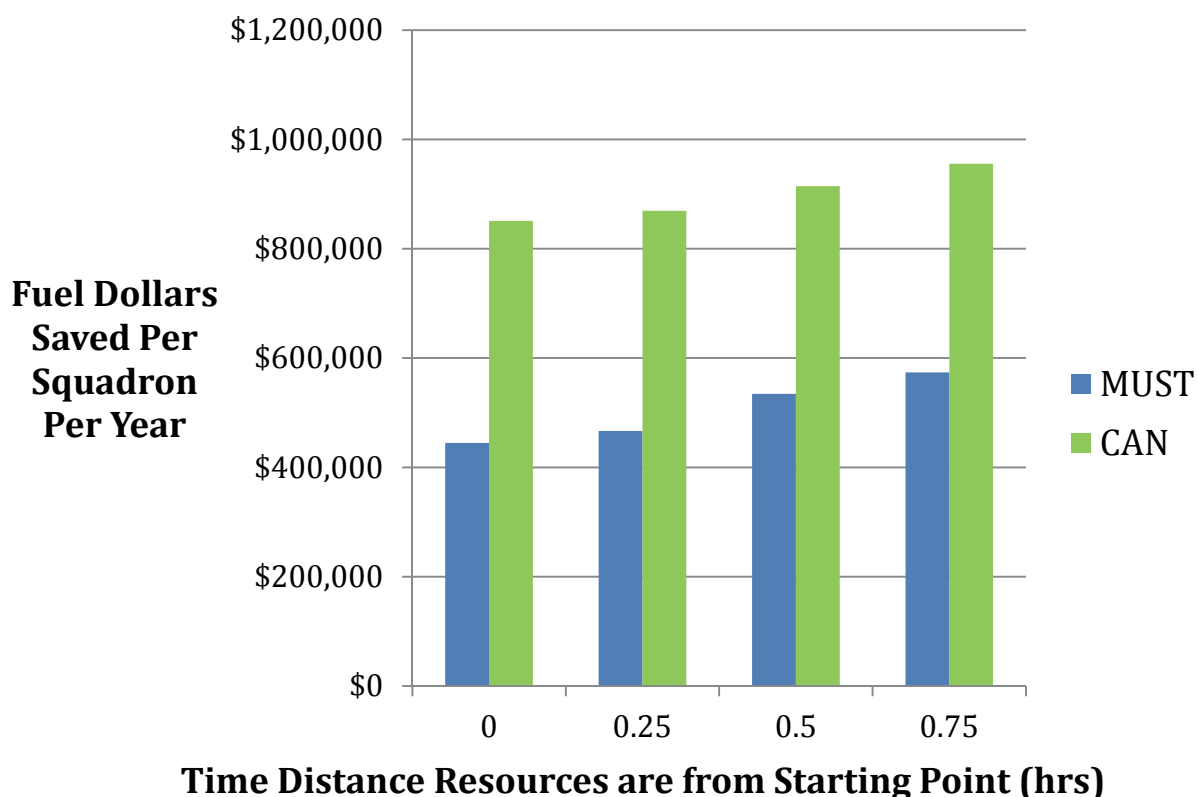
The MC-130J is a brand new aircraft; the fleet average age is 1.7 years. MC-130Hs are on average of 25.7 years old and MC-130Ps are on average 46.7 years old. The MC-130Ps are in the process of being retired.[72] The MC-130Es were retired in 2013 after having been procured in the mid-60s during the Vietnam War.[73] With differing ages, amounts of wear and tear, and maintenance and fuel requirements, each of these aircraft have different flying hour costs. As flying hour substitutions are frequently used to justify the acquisition of a simulator, it is important to understand how varying flying hour costs could affect this acquisition decision.

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[72] **"Total Force Aircraft Age"** *Air Force Almanac,* **Vol. 97, No. 05, May 2014. http://www.airforcemag.com/MagazineArchive/Pages/TableOfContents.aspx?Date=05/2014**

[73] **Thigpen, Jerry L., The Praetorian STARShip The Untold Story of the Combat Talon: Air University Press, 2001. http://www.au.af.mil/au/awc/awcgate/au/thigpen.pdf (xxxi-xxiv) p. 25**

Figure 5.1.5 shows how the presence of a co-located aircraft simulator affects yearly savings for currency training as training resource distances increase in terms of the respective flying hour costs.

Figure 5.1.5 MC-130 Co-Located Simulator Flying Hour Savings [74,75]
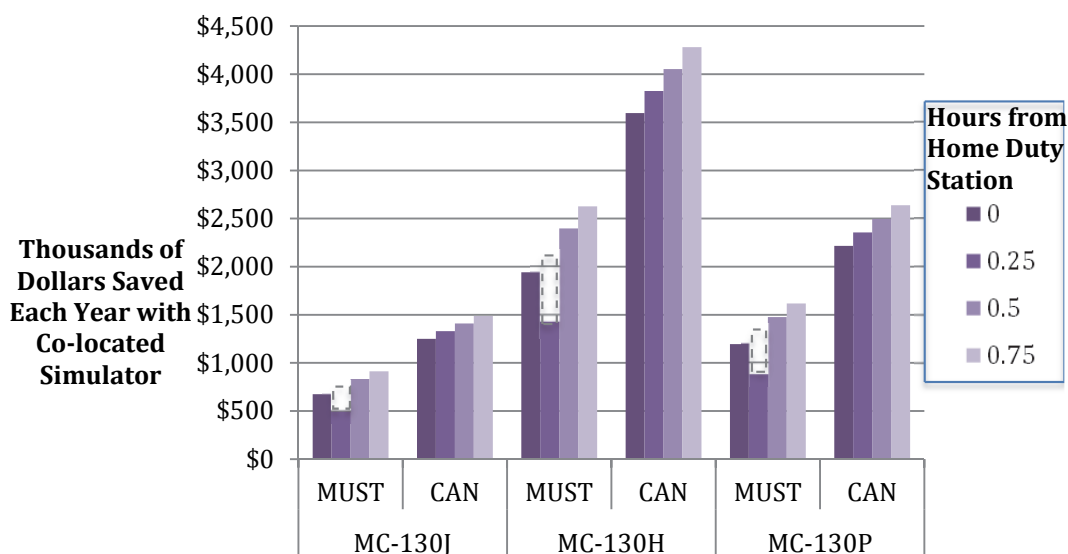
As you can see, an aircraft simulator is most easily justifiable for the MC-130H because even in a perfect world with no unpredictable factors, where training resources are located at the starting point, having a co-located aircraft simulator implemented at the "Can" level saves over $3.5M per year per squadron for currency training alone. When training resources are farther away and unpredictable factors result in attrition, the cost of training will increase. As simulators substitute for more costly training savings will occur even more quickly. The simulator will generate savings for more than just currency training, but also cost of business sorties. Considering that a strategically placed simulator could be used by multiple squadrons, savings from multiple squadrons could be attributed to paying for one simulator.

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[74] The "Must" .25 cases are computationally complex and do not complete, therefore the gray dashed lines are interpolations.

[75] The RTM used for this chart was the MC-130J's which incorporates simulators to a greater degree.

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Including all the variants of C-130s, this aircraft is the third most prevalent aircraft in the Air Force.[76] Table 5.1.3 below shows the substitution rates required to justify the initial acquisition cost of an aircraft simulator for different C-130 variants based on current flying hour cost estimates and two squadrons sharing a simulator.

Table 5.1.3 Percentage of Flying Hour Program Needed to Pay Off a $30M Simulator Shared between Two Similar Squadrons[77]

	MC-130J	MC-130H	AC-130J	AC-130H	C-130J	C-130H	EC-130J	EC-130H	HC-130J	HC-130P
$/hr	4962	14,272	4,960	11,819	5,002	9,029	12,425	3,601	6,894	10,616
5 year payoff	30%	11%	30%	13%	30%	17%	12%	42%	22%	14%
10 year payoff	15%	5%	15%	6%	15%	8%	6%	21%	11%	7%

Once the initial costs are paid off, saving from a simulator continue to be generated at a rate of the difference between the cost of a flying hour and a simulator hour. As shown above, when simulators are shared between two squadrons, their initial costs can be paid off relatively quickly even at low substitution rates. Therefore, it is better to start generating savings as soon as possible rather than waiting until flying costs increase as the aircraft ages. Notably, a MC-130J squadron substituting at the 30 percent rate is the same as a MC-130J squadron operating at the "Can" level allowable by the RTM.

Temporary Duty Assignment Training Case

Background on Temporary Duty Assignment Training

In the U.S. military, temporary duty assignments are given for a number of reasons. One of the most common reasons for a temporary duty assignment is training. Often the resources for training are not all available in every location where aircrew members are stationed. In the case

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[76] **"Total Force Aircraft Age"** *Air Force Almanac,* **Vol. 97, No. 05, May 2014.**
http://www.airforcemag.com/MagazineArchive/Pages/TableOfContents.aspx?Date=05/2014

[77] Cost of equipment only

of MC-130s in the Pacific, the duty station at Kadena Air Base, Japan was selected because "a permanent location in the region was essential for maintaining familiarity and trust between the U.S. and our allies in that part of the world," despite the fact that the availability of training resources was not ideal.[78] "While offering a central location in the Western Pacific, excellent quality of life factors, long-tours, and political stability, its only drawback was the lack of training areas. Even so, Kadena was close enough to Korea to do a significant amount of the wing's training there." [79]

Temporary duty assignments for training have several advantages. First, having established agreements in advance for training reduces the unpredictable factors that could prevent training from being completed.   Temporary duty locations are usually farther from the home duty station, but during the time at the more favorable training location, training requires less travel time, which allows for greater efficiency. In other words, more time is spent focusing on training events rather than getting from point A to point B. When aircrew members travel to locations where the training resources are more favorable, they get higher quality practice in more realistic geographical environments. Whether the temporary duty assignment arrangements are made with joint or allied organizations, it is advantageous for aircrew members to have practice working with these organizations both for coordination purposes and to train together since they may work together on real missions.

The disadvantages of temporary duty assignments for training ought to be considered as well. Once an arrangement for a temporary duty assignment is established it is advantageous, but its establishment is often difficult and time intensive. Initial travel time to the temporary duty location is costly. Personnel on temporary duty assignments receive compensation for billeting (lodging), and per diem (meals, and necessities). Not only aircrew members but also maintainers and air drop recovery personnel go on temporary duty assignments. All of these people are away

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[78] **Marion, Major Forrest L.,** *Ash Warriors: The Relocation of the 353rd Special Operations Wing June-December 1991*, **Hurlburt Field, Florida, Office, Headquarters Air Force Special Operations Command History, AFD-051228-013. p. 23.**

[79] Ibid **p. 24.**

from their families and personal lives when they go on temporary duty assignments. Increasing the frequency of temporary duty assignments can be especially hard on families.

Although working with joint and allied organizations is advantageous, there is also risk involved, which can affect the availability of training. For instance, if there were a major incident or disagreement of some kind, training could be curtailed temporarily or indefinitely.

In deciding what is the best training available, the increased access to reliable training resources that is possible with temporary duty assignments, more efficiency and focus during training, and the value of the relationships built may outweigh the added costs of temporary duty assignments, which include the initial investment of travel time, the time spent establishing agreements with other organizations, additional airmen compensation costs, and the effect on the lives of the airmen.

Methodology for the Analysis of Temporary Duty Assignment Training

Clearly, there are aspects of the temporary duty policy that cannot be quantified. Compared to all the other policies, this one has the weightiest political costs and advantages associated with it. For the purposes of this research, I tackled one piece of the costs associated with this policy. I examined the effect on the fuel cost of currency training that occurs from adjusting the proportion of temporary duty assignment training to training accomplished around the duty station. I ran two optimizations which each account for a portion of the training requirements and the relative distances of the training resources.

I looked at two different situations. At the home duty station, training resources are a 45-minute flight away. At the temporary duty station, which is a two-hour flight from the home duty station, training resources are 15 minutes away. Figure 5.2.1 below shows the relationship between the two locations.

Figure 5.2.1 Temporary Duty Location Relationship
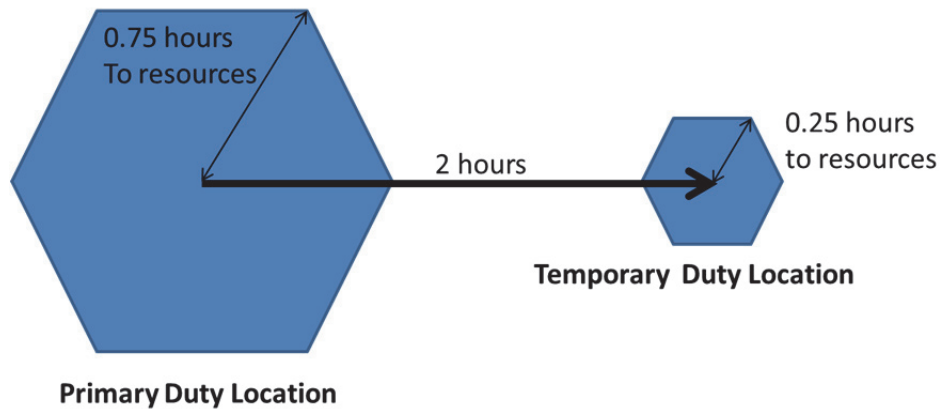
I found that increasing the proportion of temporary duty assignments in this case, results in a small but steady reduction in cost. Figure 5.2.2 shows how temporary duty assignment fuel savings accrue as the proportion of events accomplished in the more favorable location increases.

Figure 5.2.2 Temporary Duty Fuel Savings over a Year for One Squadron
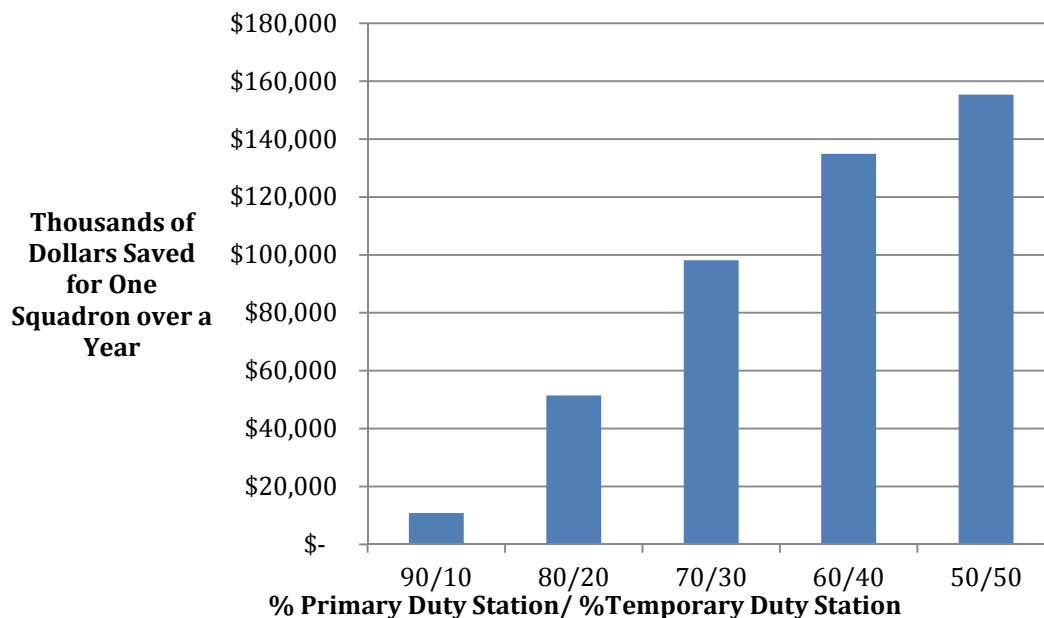
Notably this savings is calculated without including the initial cost of traveling to the temporary duty location, or the airmen compensation. The fuel cost of traveling to the location would be the number of times traveled to the temporary duty location multiplied by the fuel cost of traveling

there. As shown in Table 5.2.1 below, the fuel savings for conducting training in a more favorable location in this case does not offset the added fuel cost of a trip until 30 percent of the training is done at the temporary duty location. Notably, it would be difficult to do 30 percent of the training for a year in one trip, especially since currency training is conducted on a semi-annual basis.

Table 5.2.1 TDY Trips Justified by Fuel Dollars Saved

Proportion of TDY	Fuel Dollars Saved	Gallons	Full Trips
10%	$10,825	2926	0
20%	$54,422	13898	0
30%	$98,139	26524	1
40%	$134,921	36465	1
50%	$155,355	41988	2

This is not to say that there are no cases where the fuel savings alone would justify the trip. When comparing temporary duty assignment fuel savings in this case to the possible simulator fuel savings in this case, it can be seen that simulator savings in terms of fuel alone accrue much faster. Figure 5.2.3 below shows the contrast.

Figure 5.2.3 Simulator vs. TDY Fuel Dollar Savings in a Year
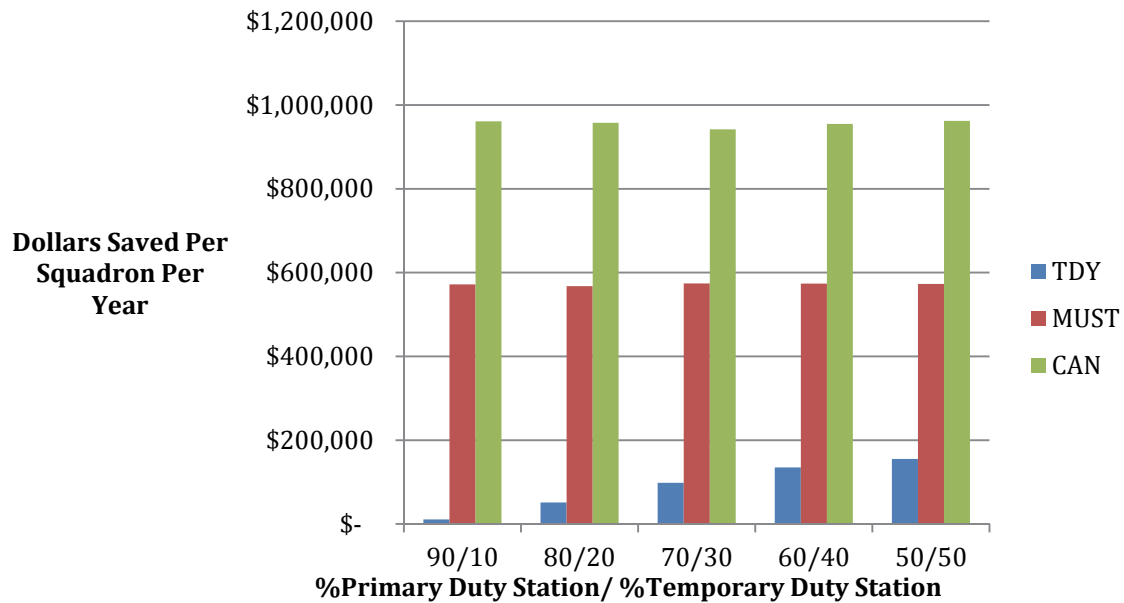
To investigate when more temporary assignments would provide a more decisive advantage solely from a cost perspective, I looked at helicopter and tiltrotor air-to-air refueling, which is one of the more distance sensitive training categories, and where the training resource was particularly far away at two hours. The result is displayed in Figure 5.2.4 below.

Figure 5.2.4 Fuel Savings from Increasing the Proportion of TDYs when Helicopter and Tiltrotor Air-to-Air Refueling Training Resources are Two Hours Away
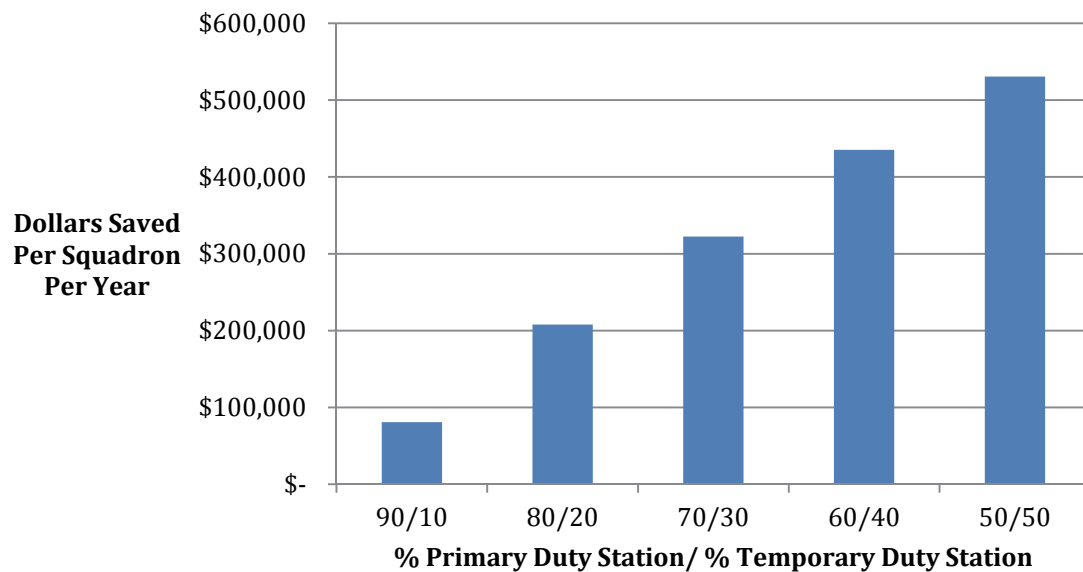
In comparison to the original scenario, this case results in significantly more savings. Table 5.2.2 shows how many trips from the home duty station to the temporary duty assignment location could be justified by these fuel savings. When 30 percent of training is conducted at a temporary duty station, the fuel savings from training in the more favorable training location could pay for four trips worth of fuel.

Table 5.2.2 TDY Trips Justified by Fuel Dollars Saved when Helicopter and Tiltrotor Air-to-Air Refueling Training Resources are Two Hours Away

Proportion of TDY	Fuel Dollars Saved	Gallons	Trips
10%	$80,741	21822	1
20%	$207,760	56151	2
30%	$322,320	87113	4
40%	$435,337	117659	5
50%	$530,751	143446	7

I also looked at a training resource less sensitive to distance electronic warfare and ran the same analysis. Figure 5.2.5 below shows the results.

Figure 5.2.5 Fuel Savings from Increasing the Proportion of TDYs when Electronic Warfare Training Resources are Two Hours Away

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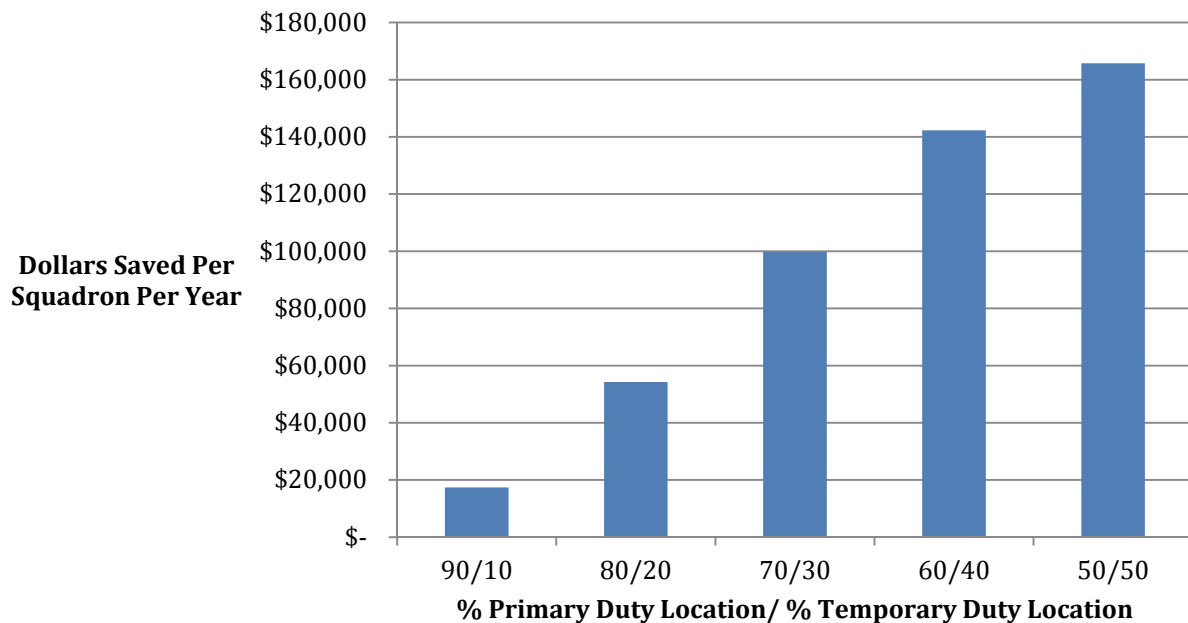
Table 5.2.3 TDY Trips Justified by Fuel Dollars Saved when Electronic Warfare Training Resources are Two Hours Away

Proportion	Fuel Dollars Saved	Gallons	Trips
10%	$80,741	4693	0
20%	$207,760	14663	0
30%	$322,320	26966	1
40%	$435,337	38453	1
50%	$530,751	44801	2

The savings with temporary duty training are not much more than they are in the baseline TDY case. At 30 percent the fuel savings would still only offset one temporary duty assignment. Therefore, it is important to realize that temporary duty assignment training is more valuable when it is substituted for training on distant training resources, especially when the training category has low supply-to-demand ratios.

Role Specialization Analysis Case

Background on Role Specialization

The primary functions of an MC-130 are infiltration, exfiltration, helicopter air-to-air refueling, and Special Operations Forces resupply. Each of these roles requires aircrew training. To mitigate costs and alleviate contingency planning due to attrition, some co-located squadrons have adopted a policy of role specialization. In economics, specialization is a concept where producers focus on producing products where they have a comparative advantage in order to expand the production curve of the entire system. While maintaining all currency standards, squadrons invest in proficiency by divvying up missions according to role. For example one squadron might focus on missions that require low-level flying and another on helicopter and tiltrotor air-to-air refueling. By focusing their resources, the squadrons are able to increase their efficiency and expand their production.

While role specialization expands the production of the two squadrons, it is important to understand its effects on production capacity. If the nation needs two squadrons to be proficient in a particular skill rather than one being proficient and one current, this approach could be problematic. Therefore, the effects of role specialization go beyond the savings associated with being more efficient.

Over time the roles of aircraft change in response to the demand for capabilities and the supply of resources. According to Jane's, the MC-130J is currently equipped with the AN/APN-241 radar.[80] A recent committee report from Congress states the following:

> The committee notes that U.S. Special Operations Command (USSOCOM) recently conducted an analysis of alternatives for MC-130J Commando II aircraft, and that this analysis led to the decision to discontinue development of the APN-241 radar and to transition to the AN/APQ-187 Silent Knight Radar. The committee understands that during contractor flight tests of the APN-241 modified for terrain following, operators and testers deemed the APN-241 unsafe and ineffective for Terrain Following/Terrain Avoidance (TF/TA) flight, and that any modification to the current APN-241 would require extensive redesign and result in a new radar system. As such, the committee supports the USSOCOM Commander's decision to accelerate transition to the AN/APQ-187 Silent Knight Radar program, and based on the justification provided to the committee from USSOCOM, recommends transferring available funding from the MC-130 Terrain Following/Terrain Avoidance Radar procurement program to higher priority programs in other budget appropriations.[81]

In a presentation made by the program manager for the acquisition of the Silent Knight Radar, the radar will be put on "69 MH-47G, 72 MH-60M, 50 CV-22, and 20 MC-130H" and is "under consideration for the 2nd line of sight radar on 50 MC-130J."[82] Given the current terrain

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[80] **"Lockheed Martin 382U/V Super Hercules," Jane's All the World's Aircraft. 2014. https://janes.ihs.com/CustomPages/Janes/DisplayPage.aspx?DocType=Reference&ItemId=+++1343364&Pub abbrev=JAWA**

[81] **114th Congress, House Report 114-102 National Defense Authorization Act for Fiscal Year 2016. http://thomas.loc.gov/cgi-bin/cpquery/?&dbname=cp114&sid=cp114cT0f3&refer=&r_n=hr102.114&item=&&&sel=TOC_394913&**

[82] **Gonzalez, LTC Hector, "AN/APQ-187 Silent Knight Radar " in *Rotary Wing*: Special Operations Forces Industry Conference. http://www.dtic.mil/ndia/2013SOFIC/SKRSOFIC2013.pdf**

following/terrain avoidance radar is deemed "unsafe and ineffective," the low-level role of the MC-130J is currently limited, but the sensor needed to fulfill this role will be on several other aircraft. As decision makers consider acquiring the second radar for the MC-130J, they must consider the extent to which the low-level role of the MC-130J can be augmented by these other aircraft.

Methodology for the Role Specialization Analysis

To analyze the cost effects on continuation training of changing the roles of the MC-130, the following methodology was created. The total number of training events was held constant and individual roles were eliminated. The events from the eliminated role are included in the pilot proficiency event category to preserve the total number of events. The Figure 5.3.1 below shows the change in the cost of currency from the baseline where training resources are half an hour away from the duty station.

Figure 5.3.1 Fuel Savings Effect of Eliminating Single Roles
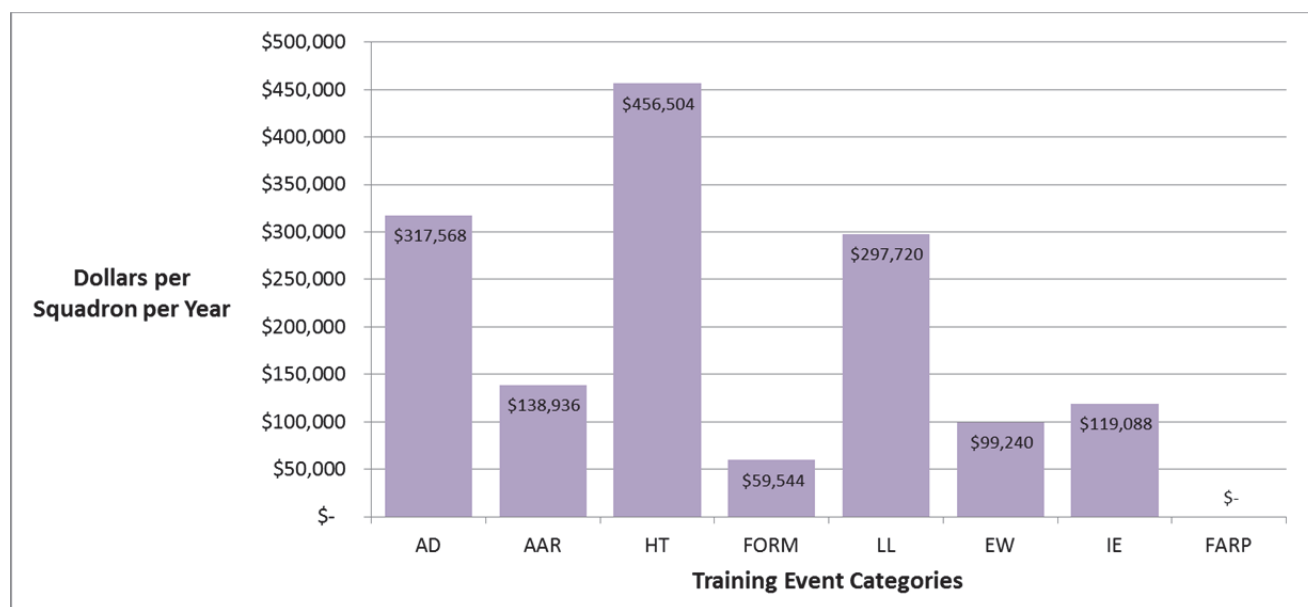
The amount of savings produced from eliminating each role is higher for the training categories with low supply to demand ratios. This means that training categories with higher demand, or numbers of training event requirements, and those with lower supply rates, cost more to conduct. Understanding the relative costs of individual training categories and events is valuable for

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understanding the tradeoffs that exist when prioritizing different types of training in preparation for a particular mission or when making budgetary decisions. In terms of fuel savings, having a simulator saves more than eliminating any role of the aircraft at the "Must" or "Can" substitution rates. When making decisions such as acquiring a sensor, or encouraging role specialization practices, it is valuable to have a framework for estimating the cost effects of the decision.

In comparison to the baseline case, none of the savings above are very compelling. The following table compares a situation where the low-level role is eliminated to the situation where the resources necessary to practice low-level flying are two hours away from the duty station. The comparison reveals greater savings for eliminating the low-level role. Rather than eliminating low-level role other cost mitigation options could be explored as well.

Table 5.3.1 Comparison of a Relatively Distant Low Level Case to No Low Level

	Low Level (2hr)	No Low Level
Flight Hours	1212	964
Flying Hours Cost ($FY15)	$6.0M	$4.8M
Pounds of Fuel	6,948,803	5,675,339
Fuel Cost (at $3.7/gallon)	$3.9M	$3.1M
Number of Sorties	230	194
Cost Difference From Baseline	+$0.9M	-$0.3M

This comparison reveals that if the low-level role which had relatively distant training resources were to be eliminated, while keeping the total number of training events constant, about $1.2 million dollars would be saved per year. In cases where particular resources are very costly it may be worthwhile to accomplish the mission another way.

Increased Attrition Results in More Contingency Plans and Higher Training Costs

Aircrew currency training does not occur in a perfect world. Many unpredictable factors contribute to attrition. Attrition results in more contingency plans and higher currency training costs. The Table 5.4.1 below describes the results of applying a uniform 50 percent attrition rate to all the training categories with a 90 percent completion rate (10 percent attrition rate) for pilot proficiency events. Aircrew members estimate that they get half of the training that is planned for them. However, pilot proficiency events alone do not require as many training resources and can usually be conducted even if all the location-based training resources fall through.

The rows in the table below each represent a contingency plan that accounts for all the remaining training to be accomplished. The first column lists the number of flying hours required to complete the plan if everything goes perfectly. The next column describes the cost of each plan in terms of the fiscal year 2015 **flying hour cost estimate**, if everything goes as planned. The next two columns are a range of **fuel** costs for the events. (Recall the baseline case fuel cost is $3.3 million.) The upper fuel cost would be incurred if the aircrew found out that a training resource was unavailable upon arrival to the location. The lower fuel cost would be the fuel cost incurred if the aircrew found out the training resource was unavailable before they left their duty station. In both cases, attrition results in currency training costing more.

Table 5.4.1 Estimated Cost of Attrition in the Baseline Case

	Hours Planned	Planned Flight Hour Cost Estimate ($FY15)	Upper Fuel Cost	Lower Fuel Cost
Plan 1	1024	$5,081,088.00	$3,281,502	$2,632,891
Plan 2	276	$1,369,512.00	$869,691	$746,637
Plan 3	84	$416,808.00	$256,550	$159,477
Plan 4	60	$297,720.00	$181,789	$162,312
Plan 5	12	$59,544.00	$36,656	$36,656
	Totals:	**$7,224,672.00**	**$4,626,188**	**$3,737,972**

Presumably, attrition due to unpredictable factors would increase the cost of training in any case. Interestingly, the types of sorties that the model picks initially tend to focus on one training category or another. As attrition enters, the sorties become more varied in terms of categories.

Having a Simulator Reduces the Impact of Attrition

Once a simulator is present it basically guarantees that all the events conducted in the simulator go from having high attrition rates to lesser attrition rates because training accomplishment is dependent on fewer factors. Additionally, having a simulator absorbs some of the costs of attrition from in-aircraft flights. For instance, if a crew had worked to make a training plan and the whole flight got cancelled for a weather or maintenance reason (that did not also affect the aircraft simulator) they could go ahead and conduct training in the simulator.[83]

Temporary duty assignments also can reduce attrition significantly. Once agreements with other organizations or nations are established, they often last for years. Training resources are reserved at predictable times during the temporary duty and are much less likely to fall through. While temporary duty assignment training might not be uniformly justifiable on a fuel savings basis, the flying hour program assumes these opportunities are rich in training.[84] This perception is likely a result of the reduction of attrition.

Attrition rates vary according to the different training resources. Comparing the actual costs of conducting all the training in a category to what the costs would be in a perfect world would reveal the magnitude of the effect of attrition. This would be useful for making decisions for prioritizing mitigation options such as role specialization or role elimination.

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[83] The current aircraft simulator does not meet the accuracy requirements to log all training events. If these events were a significant portion of the training plan, the aircrew would not be able to log them by simply stepping to the simulator instead of the aircraft. However, the work put into the plan would not be entirely wasted and some training could still be accomplished.

[84] **Kingsley, Michael J,** *Transformation Dilemma: Air Force Special Operations Command and the Role in the Future of the Air Force and Special Operations***, DTIC Document, 2003. (Appendix B)**

Comparison of Savings between Cases

As discussed above, the aircraft simulator generates more significant savings than the other policies examined in this research. A few selected cases are compared in Table 5 below to highlight this disparity. The first case is the baseline case. The next case is the flight simulator policy implemented at the baseline location at the "Can" substitution rate. The third case is the TDY policy implemented in the case where helicopter and tiltrotor refueling training is two hours away, and the TDY location is used for 30 percent of currency training. Finally, the case where the low-level flying role is eliminated is displayed.

Table 5 Comparison of Savings between Policies (One Squadron)

	Baseline	Simulator (Can 0.5)	TDY (0.5) 30%	Multirole no Low Level
Flight Hours (in plane)	1024	740	1008	964
Flying Hours Cost ($FY15)	$5.1M	$3.8M	$5.0M	$4.8M
Pounds of Fuel	6,022,000	4,343,607	5,882,607 (+trips)	5,675,340
Fuel Cost (at $3.7/gallon)	$3.3M	$2.4M	$3.2M (+trips)	$3.1M
Number of Sorties (in plane)	98	71	99	97
Savings (In terms of Flying Hour Cost)	N/A	$1.3M	$79,000 (-trips)	$298,000

As illustrated in the table above, having a co-located simulator produces the most savings of all the policies, particularly when employed at the "Can" substitution rate or above. Once the initial cost of the simulator has been covered by associated cost savings, the simulators will continue to generate savings. Temporary duty assignments could justify themselves in terms of fuel savings under certain conditions such as when a particular resource is distant from the duty station. However, this does not begin to compensate for many of the other costs associated with temporary duty assignments. The savings from eliminating a role is not very big in any of the baseline cases. However, when a particular resource becomes more costly through distance or

unpredictable factors, it may be worthwhile in terms of savings to eliminate a role, or invest in a mitigation option for reducing the costs of a particular role.

Chapter Summary

This chapter first discussed the baseline case and went over sensitivity analyses which explain how the results would be different if a different baseline case had been selected. Next, this chapter covered background on flight simulators and how this policy was modeled, followed by the results of the simulator analysis. Similarly background for the TDY policy was introduced in order to explain how this policy was considered in the model, followed by the results of the TDY analysis. Then this chapter went over role specialization background and an explanation of the methodology for this policy, followed by the results of the role specialization analysis. A brief attrition analysis was then discussed. Finally, the savings of the different policies were compared in this chapter.

Chapter 6. Conclusions

Finding #1. Key Factors that Influence MC-130 Air Crew Training

Understanding the key factors that influence the cost efficiency of MC-130 air crew training was fundamental for constructing the model. The aircraft limitations provided the parameters in which the aircraft can operate and the constraints of the model. The aircraft limitations also determined the feasibility of the sorties which were model inputs.

Understanding how resource availability affects MC-130 air crew training led to the construction of the imaginary world, in which the model operates. This foundation provided the cases for many of the sensitivity analyses. The resources needed to conduct training were also used to construct model constraints.

Observation of the unpredictable factors which lead to attrition in aircrew training flights inspired the attrition analysis. Attrition is a key source of inefficiency in MC-130 aircrew training, so all of the policies were evaluated with this in mind.

Observation revealed the policy levers available to decision makers. Having a co-located simulator, completing training on temporary duty assignments and rethinking the specialization of MC-130 roles are all relevant and currently being considered by decision makers.

Finding #2. The Cost Effects of Different Policies for Providing Continuation Training to MC-130 Air Crew

Co-located Aircraft Simulator

Having a co-located aircraft simulator provides the most significant savings of all the policies. Co-located aircraft simulators are especially valuable when operated at the "Can" substitution rate or better. When two squadrons share a simulator, savings are incurred more quickly, thus enabling the more rapid payoff of the initial costs of the aircraft simulator acquisition. Co-

located simulators are especially recommended for aircraft variants that are more costly to fly, such as the MC-130 H. Finally, it is most advantageous to have a co-located aircraft simulator when training is relatively more costly because of distance, attrition, or a combination of the two.

Temporary Duty Assignment Training

Increasing the proportion of temporary duty assignment training may produce savings in some cases. It is particularly recommended when political and training advantages outweigh the added training costs. When training is relatively more costly due to attrition or distance, it may be especially recommended to increase the proportion of training conducted on temporary duty assignments.

Role Specialization

Being able to calculate the costs of particular aircraft roles is valuable for making policies regarding role specialization. Understanding the degree to which distance and attrition contribute to the overall cost of a particular training category provides insight into cost mitigation options. Discerning and evaluating cost mitigation options is particularly valuable when some training resources tend to comprise a larger portion of the overall cost.

Finding #3 How the Costs of Different MC-130 Air Crew Training Policies Compare

Overall, acquiring a co-located aircraft simulator contributes the most significant savings. Table 6 below compares the savings from baseline of a simulator case, a temporary duty assignment case, and a role specialization case.

Table 6 Comparison of Savings between Policies (One Squadron)

	Baseline	Simulator (Can 0.5)	TDY (0.5) 30%	Multirole no Low Level
Flight Hours (in plane)	1024	740	1008	964
Flying Hours Cost ($FY15)	$5.1M	$3.8M	$5.0M	$4.8M
Pounds of Fuel	6,022,000	4,343,607	5,882,607 (+trips)	5,675,340
Fuel Cost (at $3.7/gallon)	$3.3M	$2.4M	$3.2M (+trips)	$3.1M
Number of Sorties (in plane)	98	71	99	97
Savings	**N/A**	$1.3M	$0.1M (-trips)	$0.3M

As you can see, the savings for having an aircraft simulator are $1.3M per squadron per year at the "Can" substitution rate. Conducting temporary duty assignment training at the 30 percent rate in a more favorable location, leads to a modest $0.1M in fuel savings per squadron per year. Note this amount does not cover the cost of conducting the training. Eliminating the low-level flying role would save $0.3M per squadron per year.

Appendix A: MC-130J Availability Rates

MC130J Availability Rate

	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14
AC Avail Rate	82.3	85.9	92.7	95.6	89.5	88.7	86.0	78.4	83.5	84.3	77.8	91.6	90.1
UCL	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4	97.4
CL	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6	86.6
LCL	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9	75.9
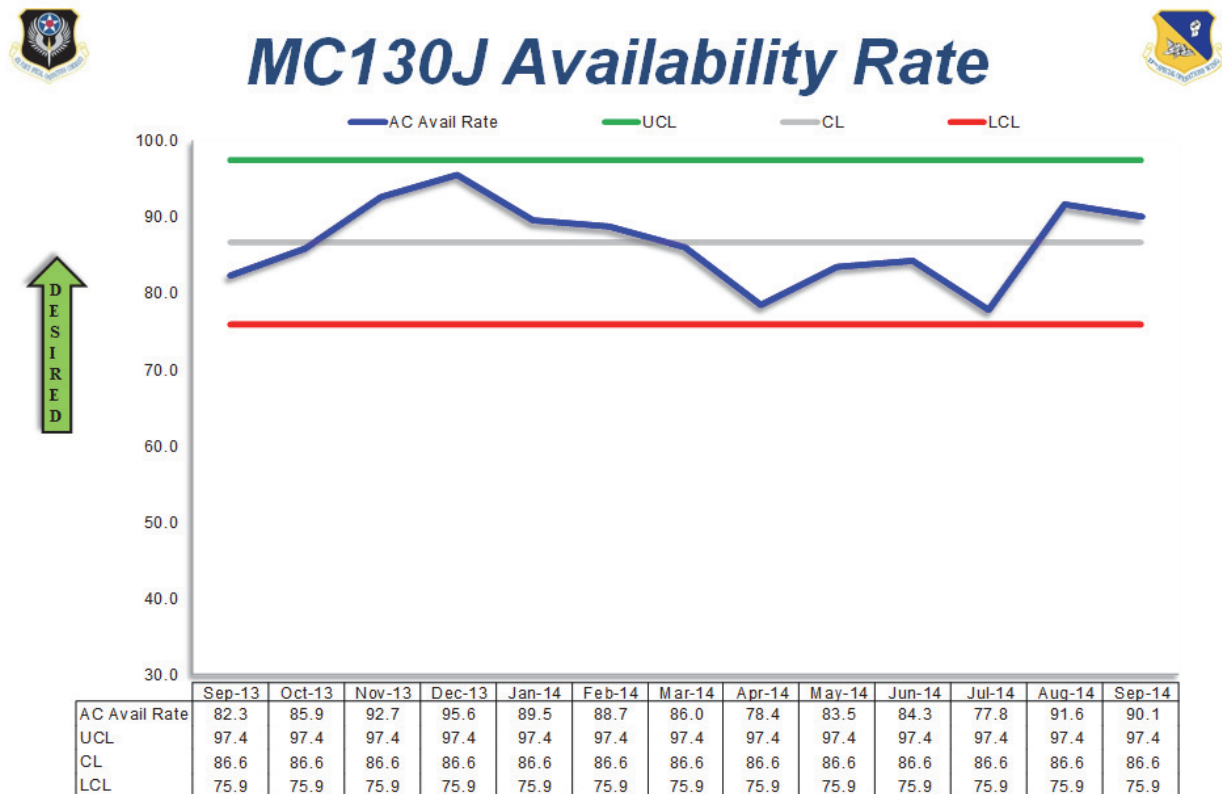
Air Commandos

AC Avail Rate = Aircraft Availability Rate

UCL= Upper Confidence Level

CL= Confidence Level

LCL= Lower Confidence Level

Appendix B: Interview Protocol

Interview questions will seek to answer the following research questions:

1. In what ways does resource availability currently affect MC-130 air crew training?
2. Given current and anticipated constraints on resources, what are the implications of exploring different air crew scheduling policies?
3. What unique challenges does the Pacific Region present for air crew training and readiness?
4. What real world considerations besides resources affect scheduling and implementation of schedules?

More specifically, some questions that will be asked are listed below. Questions will be directed based on the subject matter expertise of the interviewee. Due to the fact that the purpose of these interviews is to develop a realistic model of air crew training scheduling processes, these questions will likely lead to more specific questions about aspects of the process that are as of yet are not understood in order to identify appropriate constraints and assumptions for the model.

Understanding the Currency Training Scheduling Process and Measures:

5. How is MC-130 air crew currency training scheduling conducted?
6. How will the new MC-130J variant affect currency training scheduling? How will the new variant's currency training scheduling be the same or different from current currency training scheduling?
7. What training can be accomplished on a simulator and what training needs to be conducted on the actual platform?
8. How is readiness measured? How is currency measured? How may currency be different from proficiency? Which training qualifications are most important for maintaining readiness? Currency? Proficiency?

Currency Requirements and Completion:

9. What are the currency training requirements and what implications do they have for the scheduling system?
10. How are the currency training requirements in the Pacific different from other MC-130 bases?
11. Which currency training qualifications are typically grouped together?
12. How much flexibility is there with regard to which currency qualifications can be grouped?

13. How do operational needs affect which currency qualifications are prioritized in the system?
14. How do operational needs differ from currency training requirements? To what extent to they take precedence? Can operational missions count as currency training qualifications? If so, with what frequency can operators expect to validate currency training requirements in operational duties?
15. Is disaster relief considered an operational need? Is preparation for disaster relief incorporated in the currency training schedule directly or indirectly in any way? How has recent participation in disaster relief in the Pacific affected air crew training scheduling?

Effects of Resources on the Currency Training Scheduling Process:

16. How do resources and geography affect the currency training scheduled and actually conducted? (specifically budget, maintenance, weather, location availability etc.)
17. Are there any other factors that affect currency training scheduling? If so, please explain.
18. What are the limiting factors on the duration of currency training mission? To what extent does refueling extend/ affect currency training missions?

Crew Experience and Position:

19. What does it take to make a MC-130 Pilot/Loadmaster/CSO? How does training background or experience level affect current currency training needs?
20. What are the assumptions regarding specialties such as instructor pilots and upgrades in the scheduling system? Which training qualifications require crew member specialties or expertise? How do these training needs affect the number of people on the air frame? How many people can be trained at one time? What are the typical procedures for conducting currency training or upgrades that require expertise of some kind?
21. How are crew members prioritized for currency training? Are there any regulations for how far out of currency a crew member can be?

General Concluding Questions:

22. Are there any more assumptions or constraints that should be incorporated into the model? Is there anything else that may be important to know about MC-130 air crew training scheduling that I ought to know or consider in this modeling process?
23. Can you recommend any other experts on this matter that I should talk to? Are there any publications you would recommend I read?
24. Are there any questions you would like to ask me?

Appendix C: Informed Consent Document

Study: MC-130 Air Crew Training Scheduling Research
Principal Investigator: 1st Lt. Sarah Evans (PhD Student)
Air Force Institute of Technology Civilian Institutions Program: Pardee RAND Graduate School
Telephone: (310) 393-0411 (US)
Email: sevans@rand.org

CONSENT PROCESS OVERVIEW

I am asking you to participate in research to provide information for a research study on MC-130 air crew training scheduling. The purpose of this document is to provide you with information to help you decide whether or not to participate in this study. If you have any questions about the contents of this document, or anything not covered in this document, please feel free to ask.

PURPOSE

The purpose of this research is to examine the cost effectiveness and readiness of MC-130 air crew training in the Pacific under resource constraints and with consideration for the new crew size of MC-130J variant. My findings will be communicated in a RAND internal publication.

BENEFITS

While there will be no direct benefits to study participants, this research will make recommendations for air crew currency training scheduling processes and may have implications for optimizing multi person air crews currency training scheduling, especially in the context of resource constraints and the geographic considerations of the Pacific.

PROCEDURES

Should you decide to participate, you will be asked to answer questions regarding MC-130 air crew training scheduling. You may choose to answer all or some of the questions. You need not answer any question which you prefer not to answer, for whatever reason. You also may volunteer to provide additional information beyond what is asked if you feel it is useful or relevant. The interview ought to take around 60 minutes, but can be adjusted to accommodate your needs. There may be follow up questions or clarifications, but all data collection and analysis will be completed before September 2015.

RISKS, STRESS, OR DISCOMFORT

The risks to the participants are small and centered around any potential breach of confidentiality regarding your views on MC-130 air crew currency training scheduling. You may end the interview at any time or change your mind about your participation. If you prefer, the interview can be conducted in a different format, such as by phone, email, or in person. Interviews conducted by phone or email can give consent via email.

Should you feel that any information you provide poses a risk to you, your participation will be kept confidential.

CONFIDENTIALITY
I will keep your participation confidential unless you explicitly grant me your permission to use your name in research. In absence of your permission, I will not include your name in interview notes, audio recordings, the final publication, or any supporting presentations. No information that could personally identify you will be released or disclosed without your consent. If you grant me permission to reference you in my research, you may revoke your permission at any time before, during, or after the interview. However, please consider that if you wish to revoke your permission, this should be accomplished before the research is published in the summer or early fall of 2015.

PARTICIPATION
As discussed above, you participation is completely voluntary. If you choose to withdraw at any time, I will destroy all information regarding your participation.

CONTACT INFORMATION
I you have any further questions or concerns, please contact me directly.
1st Lt. Sarah Evans at sevans@rand.org or (310)393-0411 ext. 6351

OPTION OFAUDIO RECORDING
If you agree to be interviewed, I may ask if it is alright to audio record the interview to increase the accuracy of my note taking. If you grant me permission to audio record the interview, I will confirm your consent to do so before asking any questions. Should you change your mind at any time, you may revoke your permission. Your name will only be used to identify the audio recording if you also consent to be referenced. The audio recording will be stored on a password protected computer or in a locked drawer and will be destroyed upon completion of the research in 2015.

I am/ I am not willing to have my interview recorded for note-taking purposes.

_____(Date)

I am/ I am not willing to be referenced in this study.

_____(Date)

I have read and understood the Informed Consent Document.

_____(Sign & Date)

Appendix D: Data Safeguarding Plan

Project Description

        The purpose of this research is to potentially improve the cost effectiveness and readiness of MC-130 air crew training under resource constraints. Data to collect includes information such as how the scheduling processes are currently conducted, how resources and geography affect the scheduling process, information on typical currency levels, and how the new MC-130J variant could affect training. This information will be used to build a model of the scheduling process. Ideally, to set up a reasonable baseline for the model, recent training information such as "MC-130 pilot A accomplished X training requirement on this date," will be acquired. Additionally, once the model results come out, a short follow up survey will be conducted to capture the non-dollar costs of different scheduling policies.

Responsibility for Data Safeguarding

        I, Sarah Evans, as the principal investigator will have overall responsibility for data safeguarding. Dissertation committee members will also be responsible for safeguarding any data discussed in the process of completing the dissertation and will be instructed in how to properly safeguard sensitive material by the principal investigator.

Data Sensitivity

- *What direct or indirect identifiers will be present? To what data will they link?*

        Indirect identifiers may exist in the arrangements for meetings. It is possible that people could be indirectly identified though interview notes by inference. Direct identifiers would be signatures on informed consent forms and any voice recordings taken for notes. These identifiers would link participants to interviews and survey participation.

- *What specific data items are sensitive?*

        Names and contact information of all the respondents to all the planned interviews are sensitive. Interview notes both written and recorded could be sensitive as it may be possible to connect people with their responses by inference. Survey responses could also be sensitive if they are connected with a name in some manner. It is also possible that some of the content of the interviews may be confidential information about the training or scheduling processes themselves. However, information about the processes is being collected to inform model production, and will not contain any names or individual identifiers.

Data Transmittal

- *Which RAND groups or outside organizations are involved in receiving or transmitting data?*

        Information will be gathered directly from the Air Force MC-130 operators and experts directly to the primary investigator.

- *How are the data being transmitted?*

        Data will be transmitted in person, telephone, and by email to the primary investigator according to the Targeted RAND Internal transfer category. Interviews may be audio recorded to aid in note taking.

- *Will the client receive a copy of the data? If so, in what form?*

        No.

Client and Respondent Agreements

- *Describe any direct or indirect assurances to any person, group or organization providing the information that the data would be held in confidence or is subject to restrictions.*

Respondents for both the interviews and the survey will be assured that confidentiality will not be compromised, that identity will be kept confidential and no direct references to individuals will be made unless they give their express consent. The context of any references will be documented to preserve accuracy. Respondents' responses are completely voluntary and they will not be required to answer anything they prefer not to answer. Respondents will be given the opportunity to decide whether or not they are willing to be recorded for note-taking purposes. Recordings will be kept confidential and used to ensure accuracy. An informed consent form, which is attached, will be given to the interviewee either in hard copy form electronically or verbally depending on the interview type.

Similarly, currency information will not be associated with names and will be used to create a baseline currency level for the model. If this information is sensitive, it will not be disclosed in the publication.

Disclosure Risks

- *Who might have interest in the data and where are the greatest disclosure risks likely to occur? What are the effects of inappropriate disclosure in terms of harm?*

While AFSOC leadership and MC-130 coworkers already have access or are privy to the information sought by this research, there is a slight risk that some policy view given in an interview or survey response would be less favorably viewed by superiors or peers. It is however unlikely, that respondent would choose to share a view that poses them any risk as all responses are completely voluntary. Also, the nature of military service mitigates this risk in various ways. Firstly, service members change assignments and chains of command frequently and it is unlikely that unfavorably viewed opinions would carry over. Secondly, policy views are not a criteria considered in the promotion process unlike job performance. Thirdly, while an opinion may be viewed unfavorably, promotions are decided by a board rather than an individual. Finally, it is typical that people have different views about policies. An example that is common in the realm of air crew currency policy decisions is the use of simulators to provide a cheaper way of completing training requirements. The stereotypical opposition for the use of simulators is that training conducted in a simulator is of less quality than training conducted in an airframe. Therefore, there exists a commonly occurring paradigm where commanders and subordinates (and their peers) disagree over a policy, without expression of differing viewpoints posing any risk to individuals. In this culture, it seems likely that other policy viewpoint disagreements would be treated similarly and not be risky.

Those who wish the US military ill will could also take advantage of a disclosure and use it to target this population. This is a risk that service members face on a regular basis. This research is about training which is likely to be of less interest than actual operations which tend to be conducted differently. No classified information will be included in this research.

Audit and Monitoring Plans

- *Are any special audits or monitoring procedures to be utilized? Will the Privacy Resource Office be asked by you to audit your project prior to completion?*

No, there are not special audits or monitoring plans.

Data Safeguarding Procedures

      1. **General Data Safeguarding:**

A log will be prepared and maintained of all sensitive data in order to facilitate proper storage and disposal. The dissertation committee will be briefed on how to properly safeguard any data that is discussed or shared. It will be established that sensitive material will only be printed when absolutely necessary and will be received at the printer by an authorized person. As a rule during the research process, identifiers such as names will be deleted or modified to prevent identification. All disclosures of private information to unauthorized parties will be reported to HSPC using the RHINO reportable event form. Should RAND intranet or email be unavailable, for whatever reason, a phone report will be made and followed by a full written report.

2. **Literature Reviews:** (Not Applicable)

3. **Expert Interviews/Observation/Data Collection:**

Names and contact information will be used to make meetings and coordinate interviews and follow up questions. The purpose of all of these information gathering tasks consists of generating inputs for the model in the form of assumptions, constraints and a baseline as discussed above. Participants will be guaranteed confidentiality and sign a consent form unless they are participating by phone or email, in which case they can give written or oral consent. Throughout the rest of the project their information will be handled and stored properly in the following manner. Data will be stored on a RAND removable resource (a RAND laptop), or RAND fixed resources such as email and drops inbox and will be protected by a password. Audio recordings will be either stored on the recording device and kept in a locked drawer, or the digital files will be uploaded to a RAND laptop and protected by password.

4. **Modeling:**

Information from the expert interviews, system observation and training records will be used to create a scheduling optimization. Any names acquired will be deleted or modified so that they are unidentifiable. Names are not relevant to this process in any case.

5. **Dollar Cost Evaluation:**

Based on information about the cost of training, the cost of different scheduling policies will be evaluated and compared.

6. **Non-Dollar Cost Evaluation:**

Once the results from the model are evaluated, MC-130 experts and operators will be surveyed in order to capture non-dollar costs of different scheduling policies. As both the primary investigator as an Air Force officer and the MC-130 experts and operators, are constrained by military timelines this survey will be understandably simple and brief to accommodate these schedule constraints. Furthermore, the survey must be simple and brief because MC-130 operators and experts are unlikely to participate in a lengthy survey that is not mandatory.

7. **Dissertation Completion:**

Once the dissertation is complete, the files will be deleted by moving the files to the trash and then emptying it. Disks and other devices will be physically destroyed or disposed of in the privacy waste bins in the Santa Monica office. Audio recordings will

similarly be disposed of by deleting the files and destroying the media. All the links to individuals will be destroyed.

Appendix E: Calculating the Binomial Coefficients

The number of combinations of aircrew training categories was determined using the typical formula for determining combinations below.

Figure D.1 Combination Formula Showing Number of Combinations of Aircrew Continuation Training Categories

$$\binom{n}{r} = \frac{n!}{r!\,(n-r)!}$$

Where 'r' is the number of categories selected from a group of 'n' categories

In this case, since sortie sets can be composed of any number of aircrew training categories, the total number of sortie sets equals the sum of the combinations when selecting zero, one, two, three, four, five, six, seven, and eight aircrew training categories respectively.

As shown above, the calculation for the number of different ways that aircrew training categories can be selected for a single sortie was accomplished by first determining the number of permutations or ways the categories can be selected and then dividing that by the number of different ways that there would be repeats. For instance, a sortie set that included aerial refueling and airdrop and a sortie set which included airdrop then aerial fueling would be counted once rather than twice because they are essentially the same for the purposes of this aspect of the model.

So to reiterate, one sortie set alternative is where the aircrew only accomplishes pro-designated events on a given sortie. This leaves us with the calculation for the combinations of the eight remaining categories of aircrew qualifications. First there is one sortie set in which the aircrew could accomplish all eight categories. If the sortie set consists of selecting only one category this can be accomplished eight different ways.[85] If only two training event categories are selected,

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[85] Nine if you include Pro, but only eight if you only count the training event categories besides Pro, which has already been counted.

sortie sets can be accomplished 28 ways. Similarly if six aircrew training event categories are selected, which is the same as leaving off only two of the categories for each sortie, these categories can be combined in 28 ways. If three categories were picked for a sortie set, such as airdrop, aerial refueling, and electronic warfare, the selection can be accomplished 56 ways by mixing and matching. Correspondingly, if five aircrew training categories were selected, or three left off every selection, this also results in 56 different combinations of the categories of aircrew training. Finally when picking four categories, there are 70 ways to select aircrew training event categories.

Figure D.2 An Example Calculation of the Pick Two Aircrew Training Categories Case

$$\binom{8}{2} = \frac{8!}{2!\,(8-2)!} = \frac{8*7*6*5*4*3*2*1}{2*1*(6*5*4*3*2*1)} = \frac{56}{2} = 28$$

Therefore, the calculation of the total amount of sortie sets or combinations of aircrew training categories is as follows.

$$1 + 8 + (28\text{x}2) + (56 \times 2) + 70 = 256 \text{ sortie sets.}$$

As stated above, these calculations are combinations rather than permutations because order does not matter when determining the aircrew training events on a given sortie set. An event category is either present on the sortie or it is not. For the purpose of this model, the order of the aircrew training categories on a particular sortie is determined by the algorithm which selects the minimum distance or costs to travel all the destinations on a given route for the resources needed to accomplish a given sortie set. Therefore, when determining sortie sets, having air drop and air-to-air refueling on a sortie set is all that matters, as opposed to the order in which these events are occurring.

Appendix F: Sample Excel Based Model Input

Which training categories are present on the sortie:

		AD	AAR	HT	FORM	LL	EW	IE	FARP	NumCategories
1	None	0	0	0	0	0	0	0	0	0
2	All	1	1	1	1	1	1	1	1	8
3	Pick1_AD	1	0	0	0	0	0	0	0	1

The duration of the sortie where the travel duration is calculated by the Traveling Salesperson Model:

Flight Duration	Travel Duration	Training Duration
4	0.0	4.0
6	3.5	2.5
6	1.0	5.0

Calculations of fuel weights in thousand pounds of fuel throughout the flight ensure aircraft limitations are not broken at any point in the flight:

Flight Fuel Weight	Other Fuel Weight	Air Drop Weight(4)	Equipment Weight	Fuel Gained	Total Takeoff Weight	Total Landing Weight
24	7	0	0	0	31	7
32	12	4	5	5	53	22
35	7	4	0	0	46	7

The number of training events on a sortie are calculated using the rates of accomplishment and the time available to dedicate to each training category.

Appendix G: Python Travelling Salesperson Model

```python
import xlwt
from datetime import datetime
import random
import time
import itertools
import urllib
import csv

style0 = xlwt.easyxf('font: name Times New Roman, color-index black, bold on',
    num_format_str='#,##0.00')
style1 = xlwt.easyxf(num_format_str='D-MMM-YY')

wb = xlwt.Workbook()
ws = wb.add_sheet('A Test Sheet')

def alltours_tsp(cities):
    "Generate all possible tours of the cities and choose the shortest tour."
    return shortest_tour(alltours(cities))

def shortest_tour(tours):
    "Choose the tour with the minimum tour length."
    return min(tours, key=tour_length)
alltours = itertools.permutations

def tour_length(tour):
    "The total of distances between each pair of consecutive cities in the tour."
    return sum(distance(tour[i], tour[i-1])
           for i in range(len(tour)))

        # Cities are represented as Points, which are represented as complex numbers
Point = complex
City  = Point

def X(point):
    "The x coordinate of a point."
    return point.real

def Y(point):
    "The y coordinate of a point."
    return point.imag

def distance(A, B):
    "The distance between two points."
    return abs(A - B)
```

```
START = City(0, 0)
FARP = City(0, 0)
AD = City(0, 0.5)
AAR = City(0.433013, .25)
HT = City(0.433013, -0.25)
LL = City(0,-0.5)
EW = City(-0.433013, -0.25)
IE = City(-0.433013, 0.25)

def alltours(cities):
    "Return a list of tours, each a permutation of cities, but each one starting with the same city."
    start = first(cities)
    return [[start] + Tour(rest)
        for rest in itertools.permutations(cities - {start})]

def first(collection):
    "Start iterating over collection, and return the first element."
    return next(iter(collection))
Tour = list  # Tours are implemented as lists of cities
def alltours(cities):
    "Return a list of tours, each a permutation of cities, but each one starting with the same city."
    start = START
    return [[start] + Tour(rest)
        for rest in itertools.permutations(cities - {start})]

All = {START, AD, AAR, HT, LL, EW, IE,FARP}
Pick7_nAD = {START, AAR, HT, LL, EW, IE, FARP}
Pick1_AD = {AD}
Pick1_AAR = {AAR}
Pick1_HT = {HT}
Pick1_LL = {LL}
Pick1_EW = {EW}
Pick1_IE = {IE}
Pick1_FARP = {FARP}
Pick7_nAD = {AAR, HT, LL, EW, IE, FARP}
Pick7_nAAR = {AD, HT, LL, EW, IE, FARP}
Pick7_nHT = {AD, AAR, LL, EW, IE, FARP}
Pick7_nForm = {AD, AAR, HT, LL, EW, IE, FARP}
Pick7_nLL = {AD, AAR, HT, EW, IE, FARP}
Pick7_nEW = {AD, AAR, HT, LL, IE, FARP}
Pick7_nIE = {AD, AAR, HT, LL, EW, FARP}
Pick7_nFARP = {AD, AAR, HT, LL, EW, IE}
Pick2_AD_AAR = {AD, AAR}
Pick2_AD_HT = {AD, HT}
Pick2_AD_Form = {AD}
Pick2_AD_LL = {AD, LL}
Pick2_AD_EW = {AD, EW}
Pick2_AD_IE = {AD,  IE}
Pick2_AD_FARP = {AD, FARP}
```

Pick2_AAR_HT = {AAR, HT}
Pick2_AAR_Form = {AAR}
Pick2_AAR_LL = {AAR, LL}
Pick2_AAR_EW = {AAR, EW}
Pick2_AAR_IE = {AAR, IE}
Pick2_AAR_FARP = {AAR, FARP}
Pick2_HT_Form = {HT}
Pick2_HT_LL = {HT, LL}
Pick2_HT_EW = {HT, EW}
Pick2_HT_IE = {HT, IE}
Pick2_HT_FARP = {HT, FARP}
Pick2_Form_LL = {LL}
Pick2_Form_EW = {EW}
Pick2_Form_IE = {IE}
Pick2_Form_FARP = {FARP}
Pick2_LL_EW = {LL, EW}
Pick2_LL_IE = {LL, IE}
Pick2_LL_FARP = {LL, FARP}
Pick2_EW_IE = {EW, IE}
Pick2_EW_FARP = {EW, FARP}
Pick2_IE_FARP = {IE, FARP}
Pick6_nAD_nAAR = {HT, LL, EW, IE, FARP}
Pick6_nAD_nHT = {AAR, LL, EW, IE, FARP}
Pick6_nAD_nForm = {AAR, HT, LL, EW, IE, FARP}
Pick6_nAD_nLL = {AAR, HT, EW, IE, FARP}
Pick6_nAD_nEW = {AAR, HT, LL, IE, FARP}
Pick6_nAD_nIE = {AAR, HT, LL, EW, FARP}
Pick6_nAD_nFARP = {AAR, HT, LL, EW, IE}
Pick6_nAAR_nHT = {AD, LL, EW, IE, FARP}
Pick6_nAAR_nForm = {AD, HT, LL, EW, IE, FARP}
Pick6_nAAR_nLL = {AD, HT, EW, IE, FARP}
Pick6_nAAR_nEW = {AD, HT, LL, IE, FARP}
Pick6_nAAR_nIE = {AD, HT, LL, EW, FARP}
Pick6_nAAR_nFARP = {AD, HT, LL, EW, IE}
Pick6_nHT_nForm = {AD, AAR, LL, EW, IE, FARP}
Pick6_nHT_nLL = {AD, AAR, EW, IE, FARP}
Pick6_nHT_nEW = {AD, AAR, LL, IE, FARP}
Pick6_nHT_nIE = {AD, AAR, LL, EW, FARP}
Pick6_nHT_nFARP = {AD, AAR, LL, EW, IE}
Pick6_nForm_nLL = {AD, AAR, HT, EW, IE, FARP}
Pick6_nForm_nEW = {AD, AAR, HT, LL, IE, FARP}
Pick6_nForm_nIE = {AD, AAR, HT, LL, EW, FARP}
Pick6_nForm_nFARP = {AD, AAR, HT, LL, EW, IE}
Pick6_nLL_nEW = {AD, AAR, HT, IE, FARP}
Pick6_nLL_nIE = {AD, AAR, HT, EW, FARP}
Pick6_nLL_nFARP = {AD, AAR, HT, EW, IE}
Pick6_nEW_nIE = {AD, AAR, HT, LL, FARP}
Pick6_nEW_nFARP = {AD, AAR, HT, LL, IE}
Pick6_nIE_nFARP = {AD, AAR, HT, LL, EW}
Pick3_AD_AAR_HT = {AD, AAR, HT}

Pick3_AD_AAR_Form = {AD, AAR}
Pick3_AD_AAR_LL = {AD, AAR, LL}
Pick3_AD_AAR_EW = {AD, AAR, EW}
Pick3_AD_AAR_IE = {AD, AAR, IE}
Pick3_AD_AAR_FARP = {AD, AAR, FARP}
Pick3_AD_HT_Form = {AD, HT}
Pick3_AD_HT_LL = {AD, HT, LL}
Pick3_AD_HT_EW = {AD, HT, EW}
Pick3_AD_HT_IE = {AD, HT, IE}
Pick3_AD_HT_FARP = {AD, HT, FARP}
Pick3_AD_Form_LL = {AD, LL}
Pick3_AD_Form_EW = {AD, EW}
Pick3_AD_Form_IE = {AD, IE}
Pick3_AD_Form_FARP = {AD, FARP}
Pick3_AD_LL_EW = {AD, LL, EW}
Pick3_AD_LL_IE = {AD, LL, IE}
Pick3_AD_LL_FARP = {AD, LL, FARP}
Pick3_AD_EW_IE = {AD, EW, IE}
Pick3_AD_EW_FARP = {AD, EW, FARP}
Pick3_AD_IE_FARP = {AD, IE, FARP}
Pick3_AAR_HT_Form = {AAR, HT}
Pick3_AAR_HT_LL = {AAR, HT, LL}
Pick3_AAR_HT_EI = {AAR, HT, EW}
Pick3_AAR_HT_IE = {AAR, HT, IE}
Pick3_AAR_HT_FARP = {AAR, HT, FARP}
Pick3_AAR_Form_LL = {AAR, LL}
Pick3_AAR_Form_EW = {AAR, EW}
Pick3_AAR_Form_IE = {AAR, IE}
Pick3_AAR_Form_FARP = {AAR, FARP}
Pick3_AAR_LL_EW = {AAR, LL, EW}
Pick3_AAR_LL_IE = {AAR, LL, IE}
Pick3_AAR_LL_FARP = {AAR, LL, FARP}
Pick3_AAR_EW_IE = {AAR, EW, IE}
Pick3_AAR_EW_FARP = {AAR, EW, FARP}
Pick3_AAR_IE_FARP = {AAR, IE, FARP}
Pick3_HT_Form_LL = {HT, LL}
Pick3_HT_Form_EW = {HT, EW}
Pick3_HT_Form_IE = {HT, IE}
Pick3_HT_Form_FARP = {HT, FARP}
Pick3_HT_LL_EW = {HT, LL, EW}
Pick3_HT_LL_IE = {HT, LL, IE}
Pick3_HT_LL_FARP = {HT, LL, FARP}
Pick3_HT_EW_IE = {HT, EW, IE}
Pick3_HT_EW_FARP = {HT, EW, FARP}
Pick3_HT_IE_FARP = {HT, IE, FARP}
Pick3_Form_LL_EW = {LL, EW}
Pick3_Form_LL_IE = {LL, IE}
Pick3_Form_LL_FARP = {LL, FARP}
Pick3_Form_EW_IE = {EW, IE}
Pick3_Form_EW_FARP = {EW, FARP}

Pick3_Form_IE_FARP = {IE, FARP}
Pick3_LL_EW_IE = {LL, EW, IE}
Pick3_LL_EW_FARP = {LL, EW, FARP}
Pick3_LL_IE_FARP = {LL, IE, FARP}
Pick3_EW_IE_FARP = {EW, IE, FARP}
Pick5_nAD_nAAR_nHT = {LL, EW, IE, FARP}
Pick5_nAD_nAAR_nForm = {HT, LL, EW, IE, FARP}
Pick5_nAD_nAAR_nLL = {HT, EW, IE, FARP}
Pick5_nAD_nAAR_nEW = {HT, LL, IE, FARP}
Pick5_nAD_nAAR_nIE = {HT, LL, EW, FARP}
Pick5_nAD_nAAR_nFARP = {HT, LL, EW, IE}
Pick5_nAD_nHT_nForm = {AAR, LL, EW, IE, FARP}
Pick5_nAD_nHT_nLL = {AAR, EW, IE, FARP}
Pick5_nAD_nHT_nEW = {AAR, LL, IE, FARP}
Pick5_nAD_nHT_nIE = {AAR, LL, EW, FARP}
Pick5_nAD_nHT_nFARP = {AAR, LL, EW, IE}
Pick5_nAD_nForm_nLL = {AAR, HT, EW, IE, FARP}
Pick5_nAD_nForm_nEW = {AAR, HT, LL, IE, FARP}
Pick5_nAD_nForm_nIE = {AAR, HT, LL, EW, FARP}
Pick5_nAD_nForm_nFARP = {AAR, HT, LL, EW, IE}
Pick5_nAD_nLL_nEI = {AAR, HT, IE, FARP}
Pick5_nAD_nLL_nIE = {AAR, HT, EW, FARP}
Pick5_nAD_nLL_nFARP = {AAR, HT, EW, IE}
Pick5_nAD_nEW_nIE = {AAR, HT, LL, FARP}
Pick5_nAD_nEW_nFARP = {AAR, HT, LL, IE}
Pick5_nAD_nIE_nFARP = {AAR, HT, LL, EW}
Pick5_nAAR_nHT_nForm = {AD, LL, EW, IE, FARP}
Pick5_nAAR_nHT_nLL = {AD, EW, IE, FARP}
Pick5_nAAR_nHT_nEI = {AD, LL, IE, FARP}
Pick5_nAAR_nHT_nIE = {AD, LL, EW, FARP}
Pick5_nAAR_nHT_nFARP = {AD, LL, EW, IE}
Pick5_nAAR_nForm_nLL = {AD, HT, EW, IE, FARP}
Pick5_nAAR_nForm_nEW = {AD, HT, LL, IE, FARP}
Pick5_nAAR_nForm_nIE = {AD, HT, LL, EW, FARP}
Pick5_nAAR_nForm_nFARP = {AD, HT, LL, EW, IE}
Pick5_nAAR_nLL_nEW = {AD, HT, IE, FARP}
Pick5_nAAR_nLL_nIE = {AD, HT, EW, FARP}
Pick5_nAAR_nLL_nFARP = {AD, HT, EW, IE}
Pick5_nAAR_nEW_nIE = {AD, HT, LL, FARP}
Pick5_nAAR_nEW_nFARP = {AD, HT, LL, IE}
Pick5_nAAR_nIE_nFARP = {AD, HT, LL, EW}
Pick5_nHT_nForm_nLL = {AD, AAR, EW, IE, FARP}
Pick5_nHT_nForm_nEW = {AD, AAR, LL, IE, FARP}
Pick5_nHT_nForm_nIE = {AD, AAR, LL, EW, FARP}
Pick5_nHT_nForm_nFARP = {AD, AAR, LL, EW, IE}
Pick5_nHT_nLL_nEW = {AD, AAR, IE, FARP}
Pick5_nHT_nLL_nIE = {AD, AAR, EW, FARP}
Pick5_nHT_nLL_nFARP = {AD, AAR, EW, IE}
Pick5_nHT_nEW_nIE = {AD, AAR, LL, FARP}
Pick5_nHT_nEW_nFARP = {AD, AAR, LL, IE}

Pick5_nHT_nIE_nFARP = {AD, AAR, LL, EW}
Pick5_nForm_nLL_nEW = {AD, AAR, HT, IE, FARP}
Pick5_nForm_nLL_nIE = {AD, AAR, HT, EW, FARP}
Pick5_nForm_nLL_nFARP = {AD, AAR, HT, EW, IE}
Pick5_nForm_nEW_nIE = {AD, AAR, HT, LL, FARP}
Pick5_nForm_nEW_nFARP = {AD, AAR, HT, LL, IE}
Pick5_nForm_nIE_nFARP = {AD, AAR, HT, LL, EW}
Pick5_nLL_nEW_nIE = {AD, AAR, HT, FARP}
Pick5_nLL_nEW_nFARP = {AD, AAR, HT, IE}
Pick5_nLL_nIE_nFARP = {AD, AAR, HT, EW}
Pick5_nEW_nIE_nFARP = {AD, AAR, HT, LL}
Pick4_AD_AAR_HT_Form = {AD, AAR, HT}
Pick4_AD_AAR_HT_LL = {AD, AAR, HT, LL}
Pick4_AD_AAR_HT_EW = {AD, AAR, HT, EW}
Pick4_AD_AAR_HT_IE = {AD, AAR, HT, IE}
Pick4_AD_AAR_HT_FARP = {AD, AAR, HT, FARP}
Pick4_AD_AAR_Form_LL = {AD, AAR, LL}
Pick4_AD_AAR_Form_EW = {AD, AAR, EW}
Pick4_AD_AAR_Form_IE = {AD, AAR, IE}
Pick4_AD_AAR_Form_FARP = {AD, AAR, FARP}
Pick4_AD_AAR_LL_EW = {AD, AAR, LL, EW}
Pick4_AD_AAR_LL_IE = {AD, AAR, LL, IE}
Pick4_AD_AAR_LL_FARP = {AD, AAR, LL, FARP}
Pick4_AD_AAR_EW_IE = {AD, AAR, EW, IE}
Pick4_AD_AAR_EW_FARP = {AD, AAR, EW, FARP}
Pick4_AD_AAR_IE_FARP = {AD, AAR, IE, FARP}
Pick4_AD_HT_Form_LL = {AD, HT, LL}
Pick4_AD_HT_Form_EW = {AD, HT, EW}
Pick4_AD_HT_Form_IE = {AD, HT, IE}
Pick4_AD_HT_Form_FARP = {AD, HT, FARP}
Pick4_AD_HT_LL_EW = {AD, HT, LL, EW}
Pick4_AD_HT_LL_IE = {AD, HT, LL, IE}
Pick4_AD_HT_LL_FARP = {AD, HT, LL, FARP}
Pick4_AD_HT_EW_IE = {AD, HT, EW, IE}
Pick4_AD_HT_EW_FARP = {AD, HT, EW, FARP}
Pick4_AD_HT_IE_FARP = {AD, HT, IE, FARP}
Pick4_AD_Form_LL_EW = {AD, LL, EW}
Pick4_AD_Form_LL_IE = {AD, LL, IE}
Pick4_AD_Form_LL_FARP = {AD, LL, FARP}
Pick4_AD_Form_EW_IE = {AD, EW, IE}
Pick4_AD_Form_EW_FARP = {AD, EW, FARP}
Pick4_AD_Form_IE_FARP = {AD, IE, FARP}
Pick4_AD_LL_EW_IE = {AD, LL, EW, IE}
Pick4_AD_LL_EW_FARP = {AD, LL, EW, FARP}
Pick4_AD_LL_IE_FARP = {AD, LL, IE, FARP}
Pick4_AD_EW_IE_FARP = {AD, EW, IE, FARP}
Pick4_AAR_HT_Form_LL = {AAR, HT, LL}
Pick4_AAR_HT_Form_EW = {AAR, HT, EW}
Pick4_AAR_HT_Form_IE = {AAR, HT, IE}
Pick4_AAR_HT_Form_FARP = { AAR, HT, FARP}

Pick3_AAR_HT_LL_EW = {AAR, HT, LL, EW}
Pick3_AAR_HT_LL_IE = {AAR, HT, LL, IE}
Pick3_AAR_HT_LL_FARP = {AAR, HT, LL, FARP}
Pick4_AAR_HT_EW_IE = {AAR, HT, EW, IE}
Pick4_AAR_HT_EW_FARP = {AAR, HT, EW, FARP}
Pick4_AAR_HT_IE_FARP = {AAR, HT, IE, FARP}
Pick4_AAR_Form_LL_EW = {AAR, LL, EW}
Pick4_AAR_Form_LL_IE = {AAR, LL, IE}
Pick4_AAR_Form_LL_FARP = {AAR, LL, FARP}
Pick4_AAR_Form_EW_IE = {AAR, EW, IE}
Pick4_AAR_Form_EW_FARP = {AAR, EW, FARP}
Pick4_AAR_Form_IE_FARP = {AAR, IE, FARP}
Pick4_AAR_LL_EW_IE = {AAR, LL, EW, IE, }
Pick4_AAR_LL_EW_FARP = {AAR, LL, EW, FARP}
Pick4_AAR_LL_IE_FARP = {AAR, LL, IE, FARP}
Pick4_AAR_EW_IE_FARP = {AAR, EW, IE, FARP}
Pick4_HT_Form_LL_EW = {HT, LL, EW}
Pick4_HT_Form_LL_IE = {HT, LL, IE}
Pick4_HT_Form_LL_FARP = {HT, LL, FARP}
Pick4_HT_Form_EW_IE = {HT, EW, IE}
Pick4_HT_Form_EW_FARP = {HT, EW, FARP}
Pick4_HT_Form_IE_FARP = {HT, IE, FARP}
Pick4_HT_LL_EW_IE = {HT, LL, EW, IE}
Pick4_HT_LL_EW_FARP = {HT, LL, EW, FARP}
Pick4_HT_LL_IE_FARP = {HT, LL, IE, FARP}
Pick4_HT_EW_IE_FARP = {HT,EW, IE, FARP}
Pick4_Form_LL_EW_IE = {LL, EW, IE}
Pick4_Form_LL_EW_FARP = {LL, EW, FARP}
Pick4_Form_LL_IE_FARP = {LL, IE, FARP}
Pick4_Form_EW_IE_FARP = {EW, IE, FARP}
Pick4_LL_EW_IE_FARP = {LL, EW, IE, FARP}
collection = [All, Pick1_AD, Pick1_AAR, Pick1_HT, Pick1_LL, Pick1_EW, Pick1_IE, Pick1_FARP,
Pick7_nAD, Pick7_nAAR, Pick7_nHT, Pick7_nForm, Pick7_nLL, Pick7_nEW, Pick7_nIE, Pick7_nFARP,
Pick2_AD_AAR, Pick2_AD_HT, Pick2_AD_Form, Pick2_AD_LL, Pick2_AD_EW, Pick2_AD_IE,
Pick2_AD_FARP, Pick2_AAR_HT, Pick2_AAR_Form, Pick2_AAR_LL, Pick2_AAR_EW, Pick2_AAR_IE,
Pick2_AAR_FARP, Pick2_HT_Form, Pick2_HT_LL, Pick2_HT_EW, Pick2_HT_IE, Pick2_HT_FARP,
Pick2_Form_LL, Pick2_Form_EW, Pick2_Form_IE, Pick2_Form_FARP, Pick2_LL_EW, Pick2_LL_IE,
Pick2_LL_FARP, Pick2_EW_IE, Pick2_EW_FARP, Pick2_IE_FARP, Pick6_nAD_nAAR, Pick6_nAD_nHT,
Pick6_nAD_nForm, Pick6_nAD_nLL, Pick6_nAD_nEW, Pick6_nAD_nIE, Pick6_nAD_nFARP,
Pick6_nAAR_nHT, Pick6_nAAR_nForm, Pick6_nAAR_nLL, Pick6_nAAR_nEW, Pick6_nAAR_nIE,
Pick6_nAAR_nFARP, Pick6_nHT_nForm, Pick6_nHT_nLL, Pick6_nHT_nEW, Pick6_nHT_nIE,
Pick6_nHT_nFARP, Pick6_nForm_nLL, Pick6_nForm_nEW, Pick6_nForm_nIE, Pick6_nForm_nFARP,
Pick6_nLL_nEW, Pick6_nLL_nIE, Pick6_nLL_nFARP, Pick6_nEW_nIE, Pick6_nEW_nFARP,
Pick6_nIE_nFARP, Pick3_AD_AAR_HT, Pick3_AD_AAR_Form, Pick3_AD_AAR_LL, Pick3_AD_AAR_EW,
Pick3_AD_AAR_IE, Pick3_AD_AAR_FARP, Pick3_AD_HT_Form, Pick3_AD_HT_LL, Pick3_AD_HT_EW,
Pick3_AD_HT_IE, Pick3_AD_HT_FARP, Pick3_AD_Form_LL, Pick3_AD_Form_EW, Pick3_AD_Form_IE,
Pick3_AD_Form_FARP, Pick3_AD_LL_EW, Pick3_AD_LL_IE, Pick3_AD_LL_FARP, Pick3_AD_EW_IE,
Pick3_AD_EW_FARP, Pick3_AD_IE_FARP, Pick3_AAR_HT_Form, Pick3_AAR_HT_LL,
Pick3_AAR_HT_EI, Pick3_AAR_HT_IE, Pick3_AAR_HT_FARP, Pick3_AAR_Form_LL,
Pick3_AAR_Form_EW, Pick3_AAR_Form_IE, Pick3_AAR_Form_FARP, Pick3_AAR_LL_EW,

Pick3_AAR_LL_IE, Pick3_AAR_LL_FARP, Pick3_AAR_EW_IE, Pick3_AAR_EW_FARP,
Pick3_AAR_IE_FARP, Pick3_HT_Form_LL, Pick3_HT_Form_EW, Pick3_HT_Form_IE,
Pick3_HT_Form_FARP, Pick3_HT_LL_EW, Pick3_HT_LL_IE, Pick3_HT_LL_FARP, Pick3_HT_EW_IE,
Pick3_HT_EW_FARP, Pick3_HT_IE_FARP, Pick3_Form_LL_EW, Pick3_Form_LL_IE,
Pick3_Form_LL_FARP, Pick3_Form_EW_IE, Pick3_Form_EW_FARP, Pick3_Form_IE_FARP,
Pick3_LL_EW_IE, Pick3_LL_EW_FARP, Pick3_LL_IE_FARP, Pick3_EW_IE_FARP,
Pick5_nAD_nAAR_nHT, Pick5_nAD_nAAR_nForm, Pick5_nAD_nAAR_nLL, Pick5_nAD_nAAR_nEW,
Pick5_nAD_nAAR_nIE, Pick5_nAD_nAAR_nFARP, Pick5_nAD_nHT_nForm, Pick5_nAD_nHT_nLL,
Pick5_nAD_nHT_nEW, Pick5_nAD_nHT_nIE, Pick5_nAD_nHT_nFARP, Pick5_nAD_nForm_nLL,
Pick5_nAD_nForm_nEW, Pick5_nAD_nForm_nIE, Pick5_nAD_nForm_nFARP, Pick5_nAD_nLL_nEI,
Pick5_nAD_nLL_nIE, Pick5_nAD_nLL_nFARP, Pick5_nAD_nEW_nIE, Pick5_nAD_nEW_nFARP,
Pick5_nAD_nIE_nFARP, Pick5_nAAR_nHT_nForm, Pick5_nAAR_nHT_nLL, Pick5_nAAR_nHT_nEI,
Pick5_nAAR_nHT_nIE, Pick5_nAAR_nHT_nFARP, Pick5_nAAR_nForm_nLL,
Pick5_nAAR_nForm_nEW, Pick5_nAAR_nForm_nIE, Pick5_nAAR_nForm_nFARP,
Pick5_nAAR_nLL_nEW, Pick5_nAAR_nLL_nIE, Pick5_nAAR_nLL_nFARP, Pick5_nAAR_nEW_nIE,
Pick5_nAAR_nEW_nFARP, Pick5_nAAR_nIE_nFARP, Pick5_nHT_nForm_nLL,
Pick5_nHT_nForm_nEW, Pick5_nHT_nForm_nIE, Pick5_nHT_nForm_nFARP, Pick5_nHT_nLL_nEW,
Pick5_nHT_nLL_nIE, Pick5_nHT_nLL_nFARP, Pick5_nHT_nEW_nIE, Pick5_nHT_nEW_nFARP,
Pick5_nHT_nIE_nFARP, Pick5_nForm_nLL_nEW, Pick5_nForm_nLL_nIE, Pick5_nForm_nLL_nFARP,
Pick5_nForm_nEW_nIE, Pick5_nForm_nEW_nFARP, Pick5_nForm_nIE_nFARP, Pick5_nLL_nEW_nIE,
Pick5_nLL_nEW_nFARP, Pick5_nLL_nIE_nFARP, Pick5_nEW_nIE_nFARP, Pick4_AD_AAR_HT_Form,
Pick4_AD_AAR_HT_LL, Pick4_AD_AAR_HT_EW, Pick4_AD_AAR_HT_IE, Pick4_AD_AAR_HT_FARP,
Pick4_AD_AAR_Form_LL, Pick4_AD_AAR_Form_EW, Pick4_AD_AAR_Form_IE,
Pick4_AD_AAR_Form_FARP, Pick4_AD_AAR_LL_EW, Pick4_AD_AAR_LL_IE, Pick4_AD_AAR_LL_FARP,
Pick4_AD_AAR_EW_IE, Pick4_AD_AAR_EW_FARP, Pick4_AD_AAR_IE_FARP, Pick4_AD_HT_Form_LL,
Pick4_AD_HT_Form_EW, Pick4_AD_HT_Form_IE, Pick4_AD_HT_Form_FARP, Pick4_AD_HT_LL_EW,
Pick4_AD_HT_LL_IE, Pick4_AD_HT_LL_FARP, Pick4_AD_HT_EW_IE, Pick4_AD_HT_EW_FARP,
Pick4_AD_HT_IE_FARP, Pick4_AD_Form_LL_EW, Pick4_AD_Form_LL_IE, Pick4_AD_Form_LL_FARP,
Pick4_AD_Form_EW_IE, Pick4_AD_Form_EW_FARP, Pick4_AD_Form_IE_FARP, Pick4_AD_LL_EW_IE,
Pick4_AD_LL_EW_FARP, Pick4_AD_LL_IE_FARP, Pick4_AD_EW_IE_FARP, Pick4_AAR_HT_Form_LL,
Pick4_AAR_HT_Form_EW, Pick4_AAR_HT_Form_IE, Pick4_AAR_HT_Form_FARP,
Pick3_AAR_HT_LL_EW, Pick3_AAR_HT_LL_IE, Pick3_AAR_HT_LL_FARP, Pick4_AAR_HT_EW_IE,
Pick4_AAR_HT_EW_FARP, Pick4_AAR_HT_IE_FARP, Pick4_AAR_Form_LL_EW,
Pick4_AAR_Form_LL_IE, Pick4_AAR_Form_LL_FARP, Pick4_AAR_Form_EW_IE,
Pick4_AAR_Form_EW_FARP, Pick4_AAR_Form_IE_FARP, Pick4_AAR_LL_EW_IE,
Pick4_AAR_LL_EW_FARP, Pick4_AAR_LL_IE_FARP, Pick4_AAR_EW_IE_FARP,
Pick4_HT_Form_LL_EW, Pick4_HT_Form_LL_IE, Pick4_HT_Form_LL_FARP, Pick4_HT_Form_EW_IE,
Pick4_HT_Form_EW_FARP, Pick4_HT_Form_IE_FARP, Pick4_HT_LL_EW_IE, Pick4_HT_LL_EW_FARP,
Pick4_HT_LL_IE_FARP, Pick4_HT_EW_IE_FARP, Pick4_Form_LL_EW_IE, Pick4_Form_LL_EW_FARP,
Pick4_Form_LL_IE_FARP, Pick4_Form_EW_IE_FARP, Pick4_LL_EW_IE_FARP]
i=0
for x in collection:
        n=tour_length(alltours_tsp(x))
        ws.write(i, 1, n, style0)
        i=i+1

wb.save('0.5.xls')

Appendix H: Sample GLPK Model

```
#Baseline Model (0.5 Hour Time Distance and No Co-located Simulator with No Attrition)
param f{i in 1..321}; # fuel required by sortie profile i
param p; # Flying hour program fuel
param r{i in 1..321, k in 1..11};
param q{k in 1..11}; # number of each category required per period
param x{k in 1..11}; # availability of each resource for the period
param a{k in 1..11}; # Substitutions allowed
param g{i in 1..321}; # Simulator sortie indicator
var s{i in 1..321} integer; #

minimize fuel: sum{i in 1..321} s[i]*f[i];

s.t. FlyingHourProgram : sum{i in 1..321} s[i]*f[i] <= p;
s.t. Events{k in 1..11}: q[k]<= sum{i in 1..321} s[i]*r[i,k];
s.t. ResourcesAvailable{k in 1..11}: sum{i in 1..321} s[i]*r[i,k] <= x[k]*sum{i in 1..321} s[i];
s.t. SubstitutionsAllowed{k in 1..11}:sum{i in 1..321} s[i]*r[i,k]*g[i] <= a[k];
s.t. PositiveValues{i in 1..321}: s[i]>=0;
solve;
printf {i in 1..321}: "%s = %i\n", i, s[i] > "BALL.5.txt";
data;

param p := Gas in 2000 hour Flying Hour Program budget;

param q :=
1  # AD number needed for currency
2 # AAR number needed for currency
3 # HT number needed for currency
4 # FORM number needed for currency
5 # LL number needed for currency
6 # EW number needed for currency
7 # IE number needed for currency
8 # FARP number needed for currency
9 # PRO number needed for currency
10 # Night number needed for currency
11 # Extra number needed for currency
;

param a :=
1 # number of k category (AD) allowed for simulator substitution
2 # number of k category (AAR) allowed for simulator substitution
3 # number of k category (HT) allowed for simulator substitution
4 # number of k category (FORM) allowed for simulator substitution
5 # number of k category (LL) allowed for simulator substitution
6 # number of k category (EW) allowed for simulator substitution
```

7 # number of k category (IE) allowed for simulator substitution
8 # number of k category (FARP) allowed for simulator substitution
9 # number of k category (PRO) allowed for simulator substitution
10 # number of k category (Night) allowed for simulator substitution
11 # number of k category (Extra) allowed for simulator substitution ;

param x :=
1 1 # what percent of the time are all the resources for Airdrop available?
2 1 # what percent of the time are all the resources for Aerial Refueling available?
3 1 # what percent of the time are all the resources for Helicopter Tilt Rotor Refueling available?
4 1 # what percent of the time are all the resources for Formation available?
5 1 # what percent of the time are all the resources for Low Level available?
6 1 # what percent of the time are all the resources for Electronic Warfare available?
7 1 # what percent of the time are all the resources for Infiltration and Exfiltration available?
8 1 # what percent of the time are all the resources for FARP available?
9 1 # what percent of the time are all the resources for PRO available?
10 1 # what percent of the time are all the resources for NIGHT available?
11 1; # what percent of the time are all the resources for SIM available?

param f := #(Fuel needed to complete each feasible sortie, the results of input spreadsheet calculations)
1   24
...
321   0
;

param g :=#(1's designate which sorties are simulator sorties)
1 0
..
321 0
;
param r :=#(designates the events of each type present on a feasible sortie, the result of input spreadsheet calculations)
1   1   0
1   2   0
1   3   0
1   4   0
1   5   0
1   6   0
1   7   0
1   8   0
1   9   30
1   10   0
1   11   0

... (77 pages later...)

321   1   0
321   2   0

```
321    3      0
321    4      0
321    5      0
321    6      0
321    7      0
321    8      0
321    9      0
321    10     0
321    11     0
;
end;
```

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